M. Dollo

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P-128

SpARC
Space Automation
& Robotics Center

RoMPS Concept Review
Automatic Control of Space Robot

NASA Goddard Space Flight Center

Prepared under NASA Grant NAG-5-1517

Environmental Research Institute of Michigan
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May 16, 1991

RoMPS Electrical & Software Systems Drawing Index

Rev: 5/14/91

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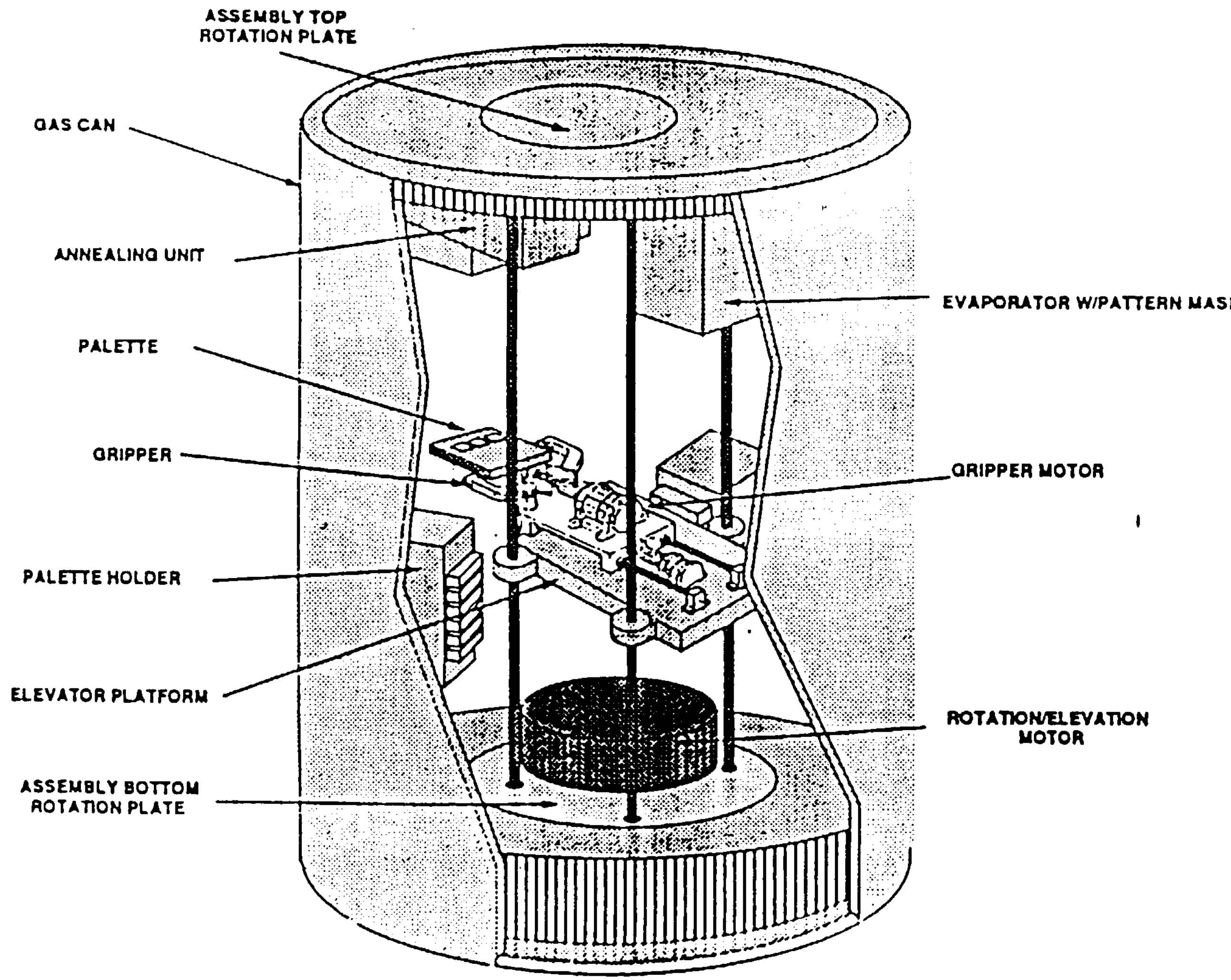
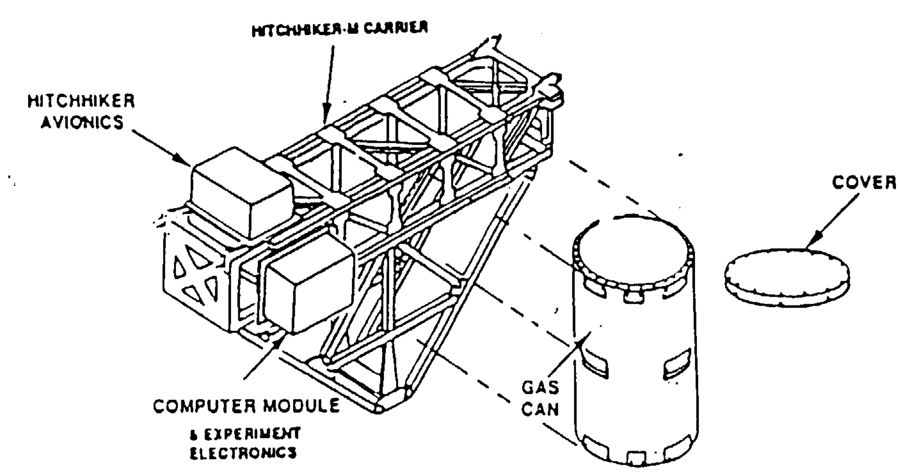
System Concept

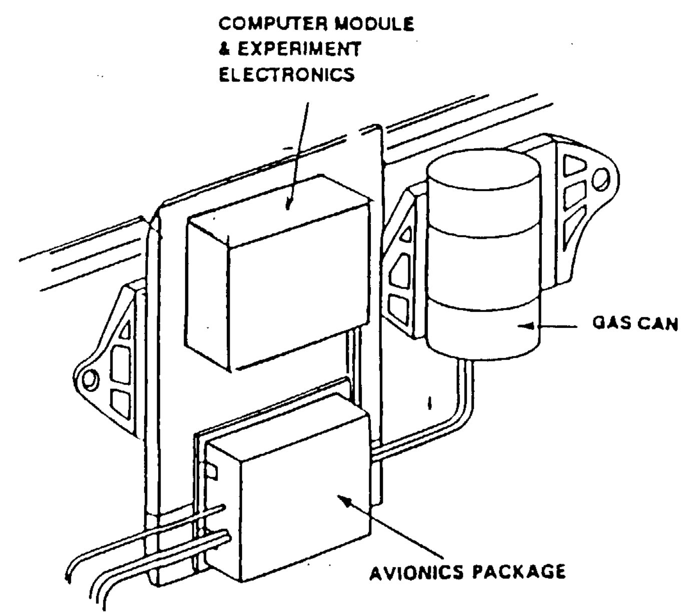
GAS CAN CONCEPT LAYOUT



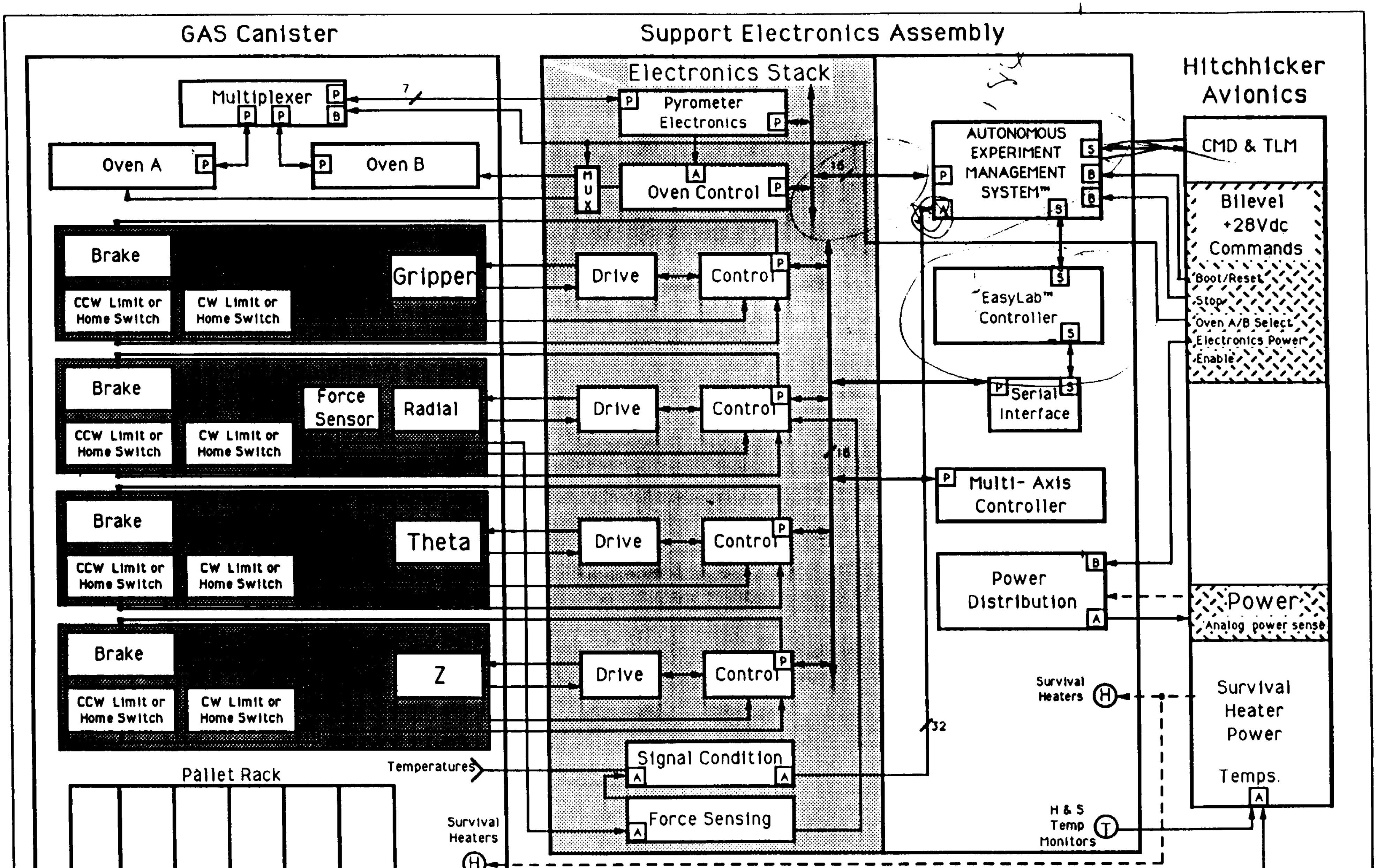
CARRIER OPTIONS



HITCHHIKER-M



HITCHHIKER-G



ENGINEER L. M. Tomko	DRAFTSMAN X. X. XXXXXXX
SPACE AUTOMATION & ROBOTICS CENTER ENVIRONMENTAL RESEARCH INSTITUTE of MI ANN ARBOR, MI	System Block Diagram RoPMS Concept RoMPS XXXXXXXXXXX

DATE
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AUTONOMOUS EXPERIMENT MANAGEMENT SYSTEM

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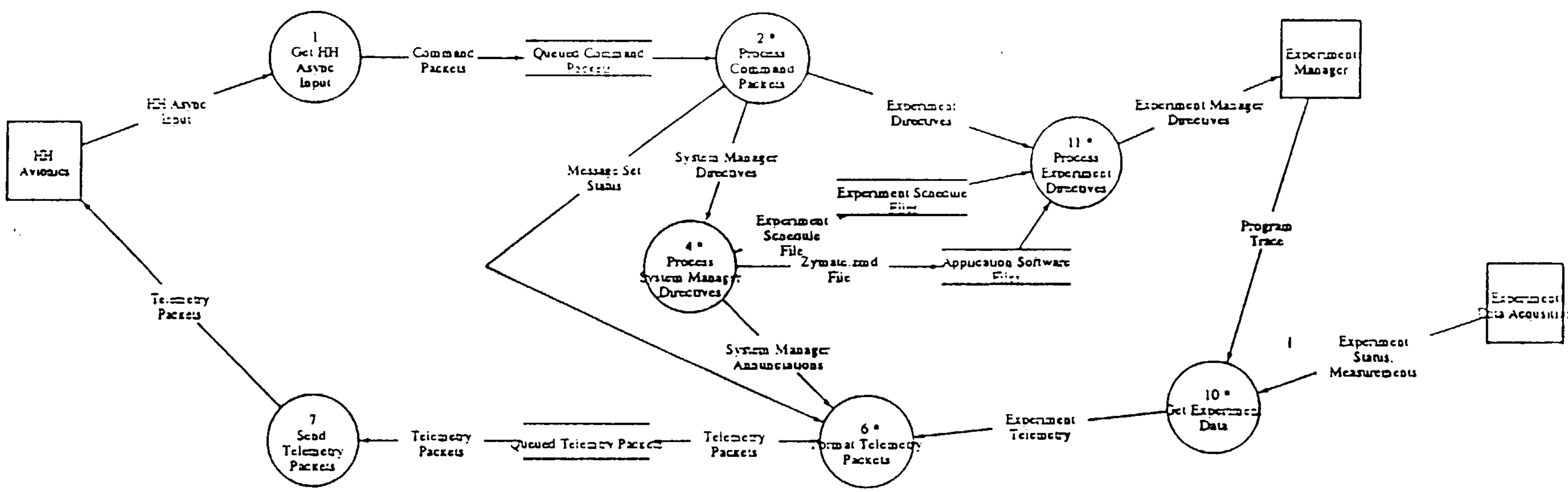

SpARC 051491/ME01

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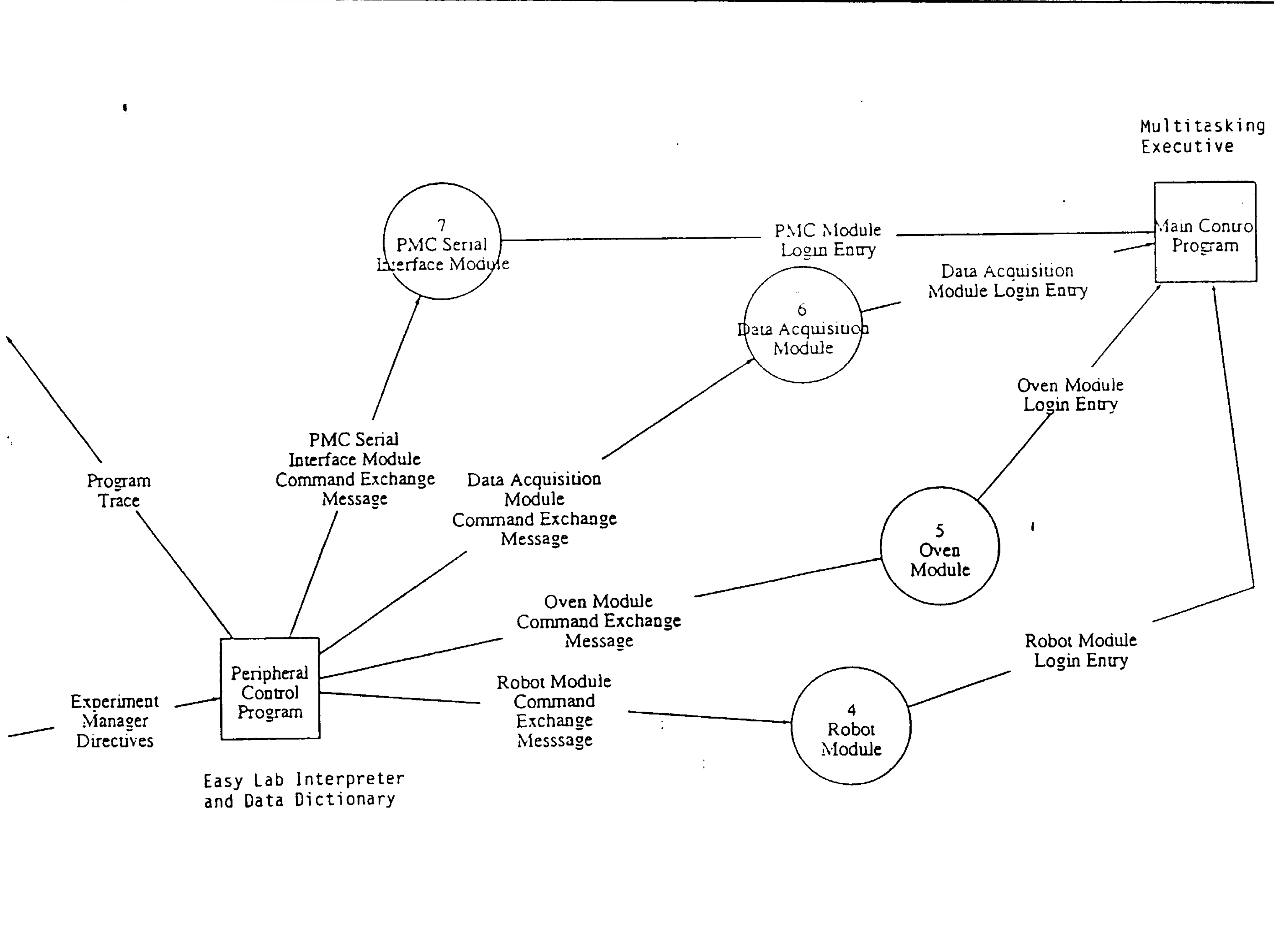
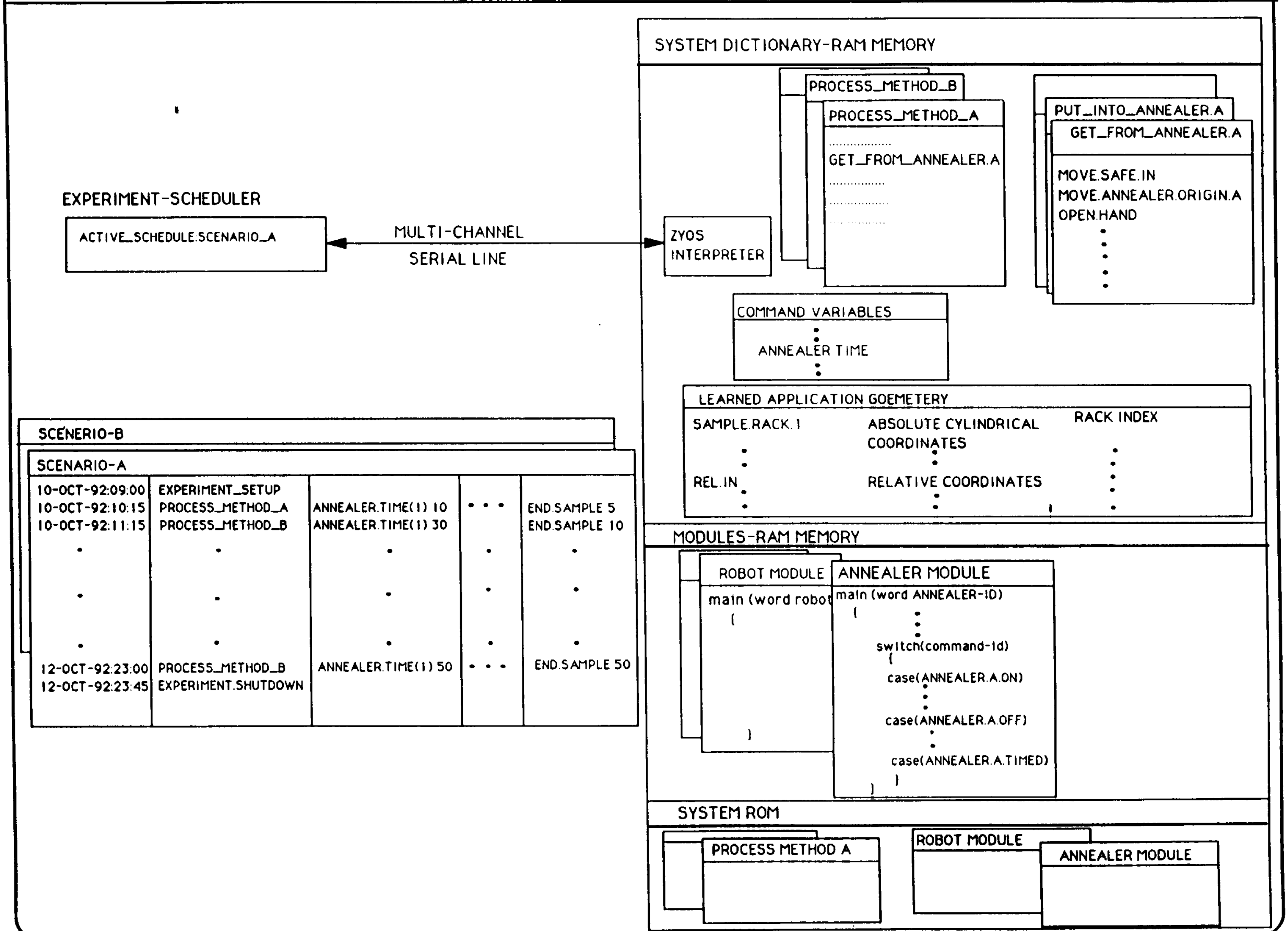
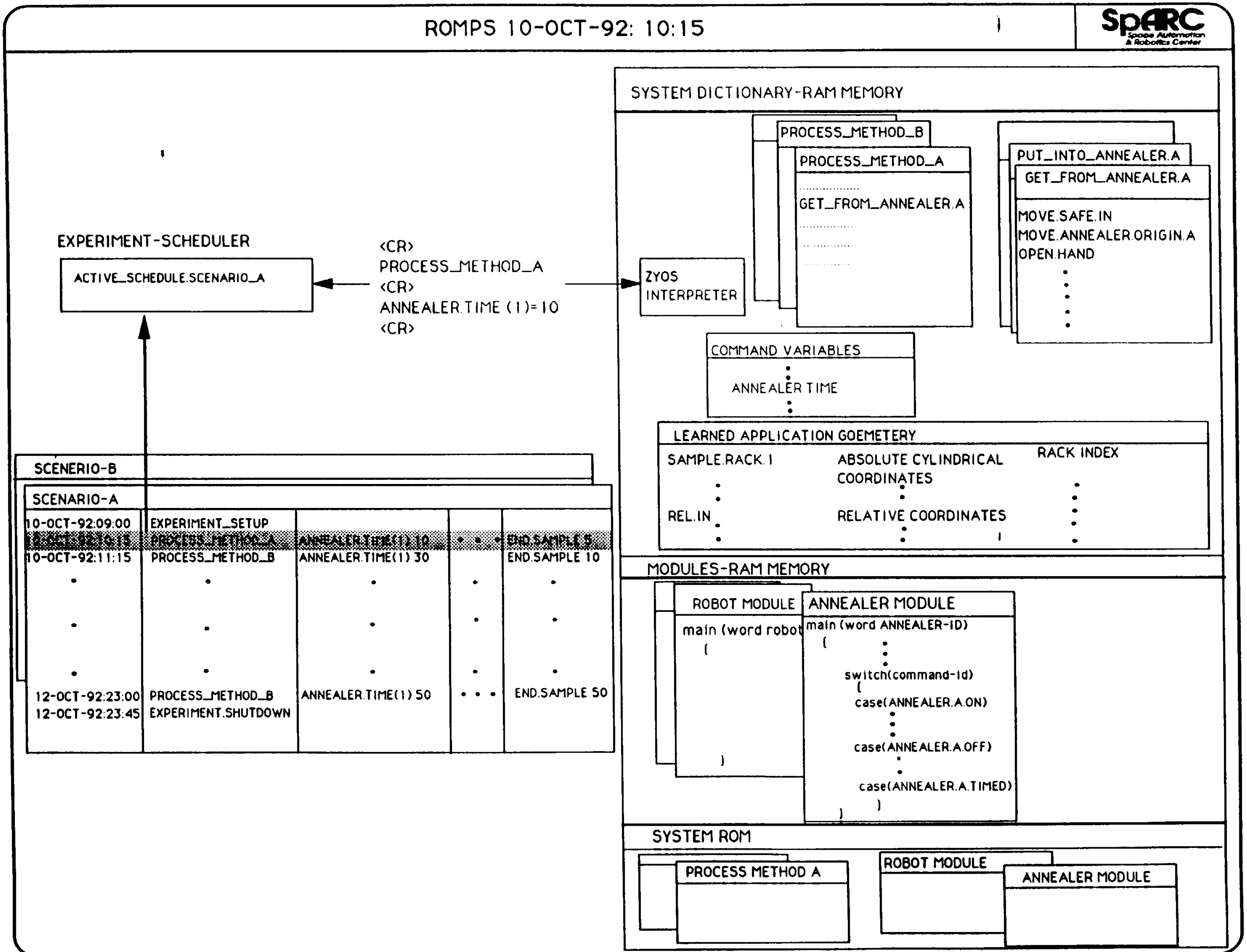
ZYMATE CONTROLLER

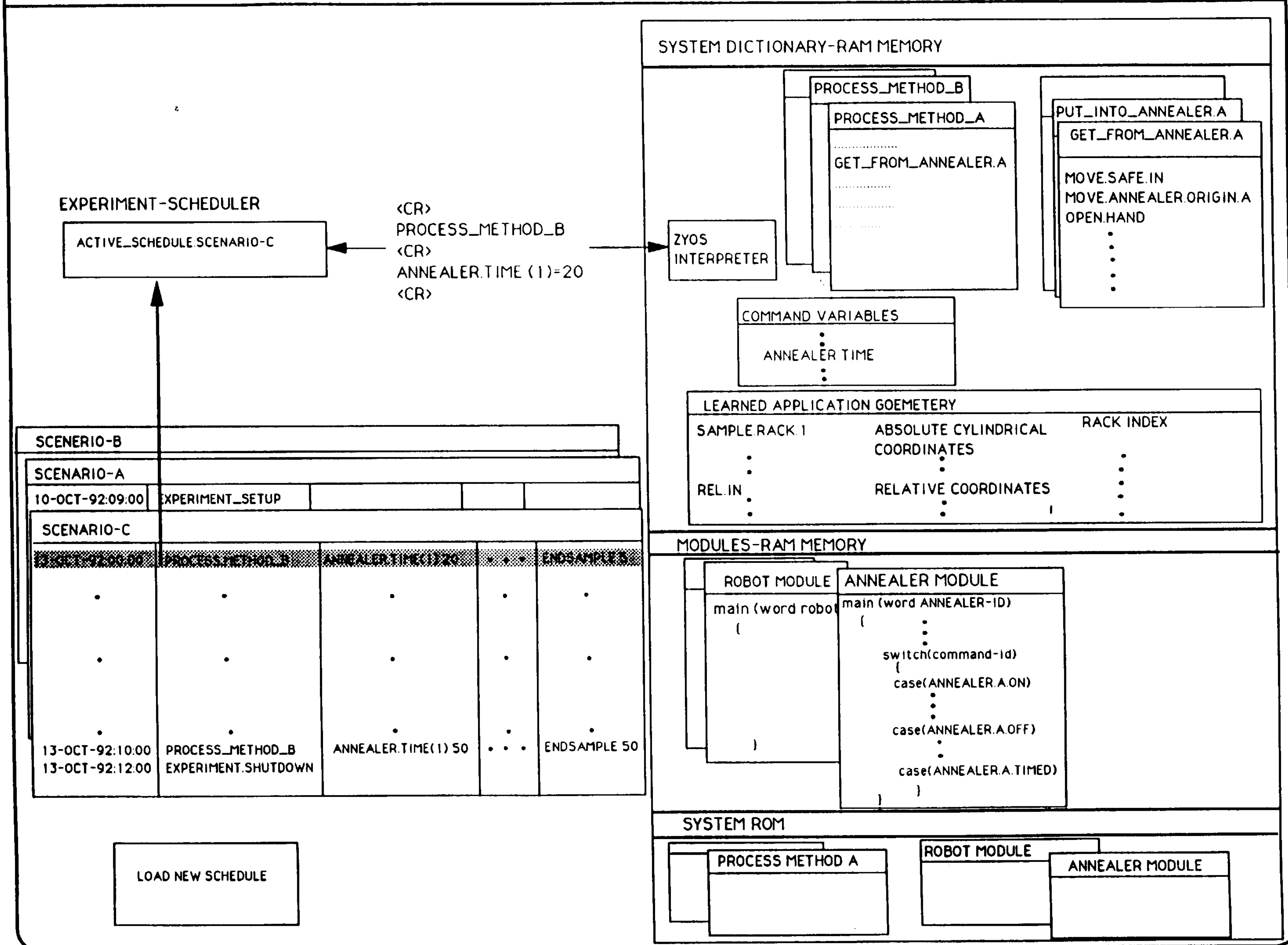


ROMPS INITIAL CONFIGURATION

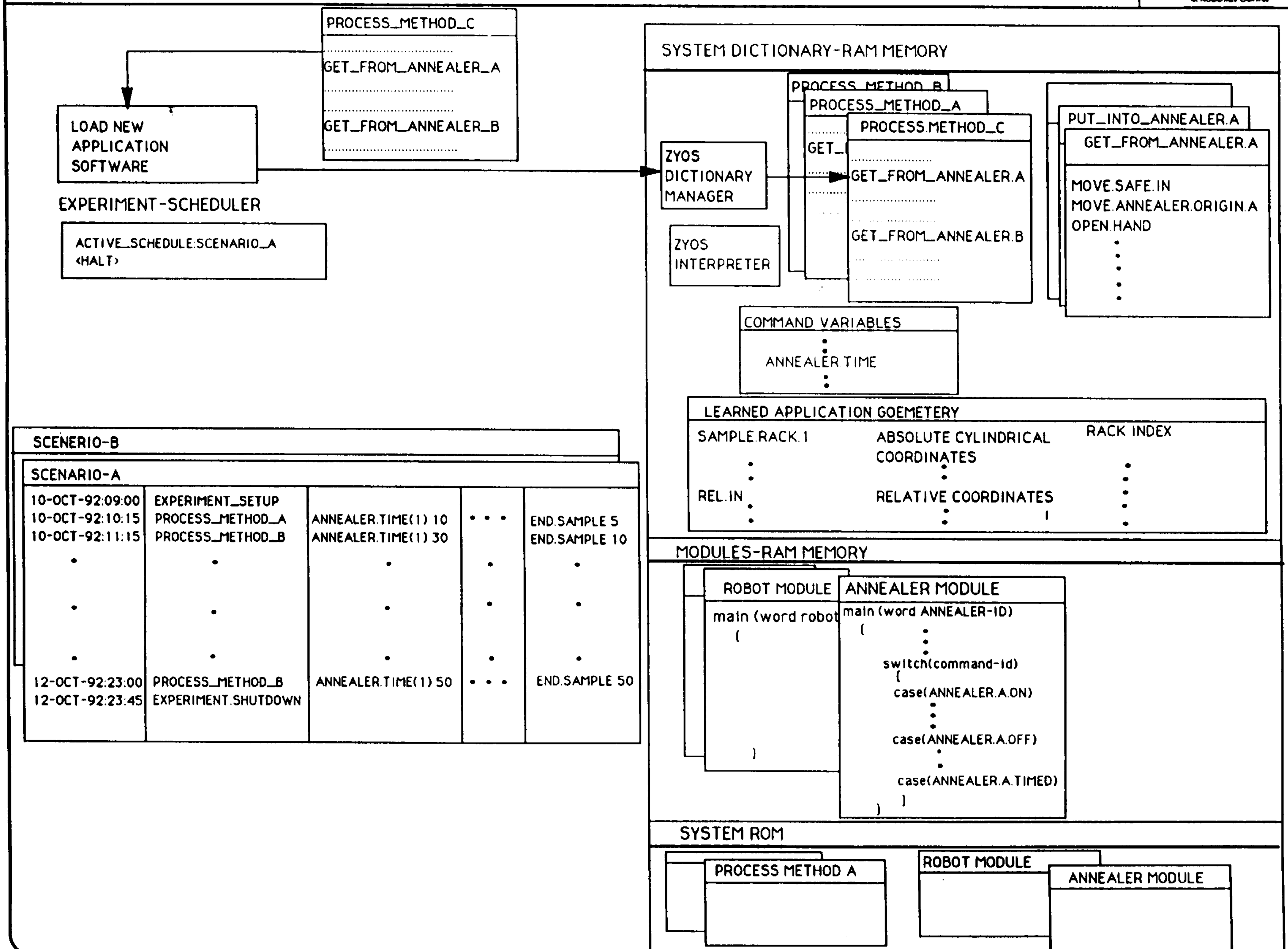



ROMPS 10-OCT-92: 10:15
SpARC Space Automation & Robotics Center
EXPERIMENT-SCHEDULER
ACTIVE_SCHEDULE.SCENARIO_A
<CR>
PROCESS_METHOD_A
<CR>
ANNEALER.TIME (1)=10
<CR>
ZYOS INTERPRETER
SCENERIO-B
SCENARIO-A
10-OCT-92:09:00 EXPERIMENT_SETUP
10-OCT-92:10:15 PROCESS_METHOD_A ANNEALER.TIME(1) 10 END.SAMPLE 5
10-OCT-92:11:15 PROCESS_METHOD_B ANNEALER.TIME(1) 30 END.SAMPLE 10
12-OCT-92:23:00 PROCESS_METHOD_B ANNEALER.TIME(1) 50 END.SAMPLE 50
12-OCT-92:23:45 EXPERIMENT.SHUTDOWN
SYSTEM DICTIONARY-RAM MEMORY
PROCESS_METHOD_B
PROCESS_METHOD_A
GET_FROM_ANNEALER.A
PUT_INTO_ANNEALER.A
GET_FROM_ANNEALER.A
MOVE.SAFE.IN
MOVE.ANNEALER.ORIGIN.A
OPEN.HAND
COMMAND VARIABLES
ANNEALER TIME
LEARNED APPLICATION GOEMETERY
SAMPLE.RACK.1
REL.IN
ABSOLUTE CYLINDRICAL COORDINATES
RELATIVE COORDINATES
RACK INDEX
MODULES-RAM MEMORY
ROBOT MODULE
main (word robot
{
}
ANNEALER MODULE
main (word ANNEALER-ID)
{
switch(command-id)
{
case(ANNEALER.A.ON)
case(ANNEALER.A.OFF)
case(ANNEALER.A.TIMED)
}
}
SYSTEM ROM
PROCESS METHOD A
ROBOT MODULE
ANNEALER MODULE

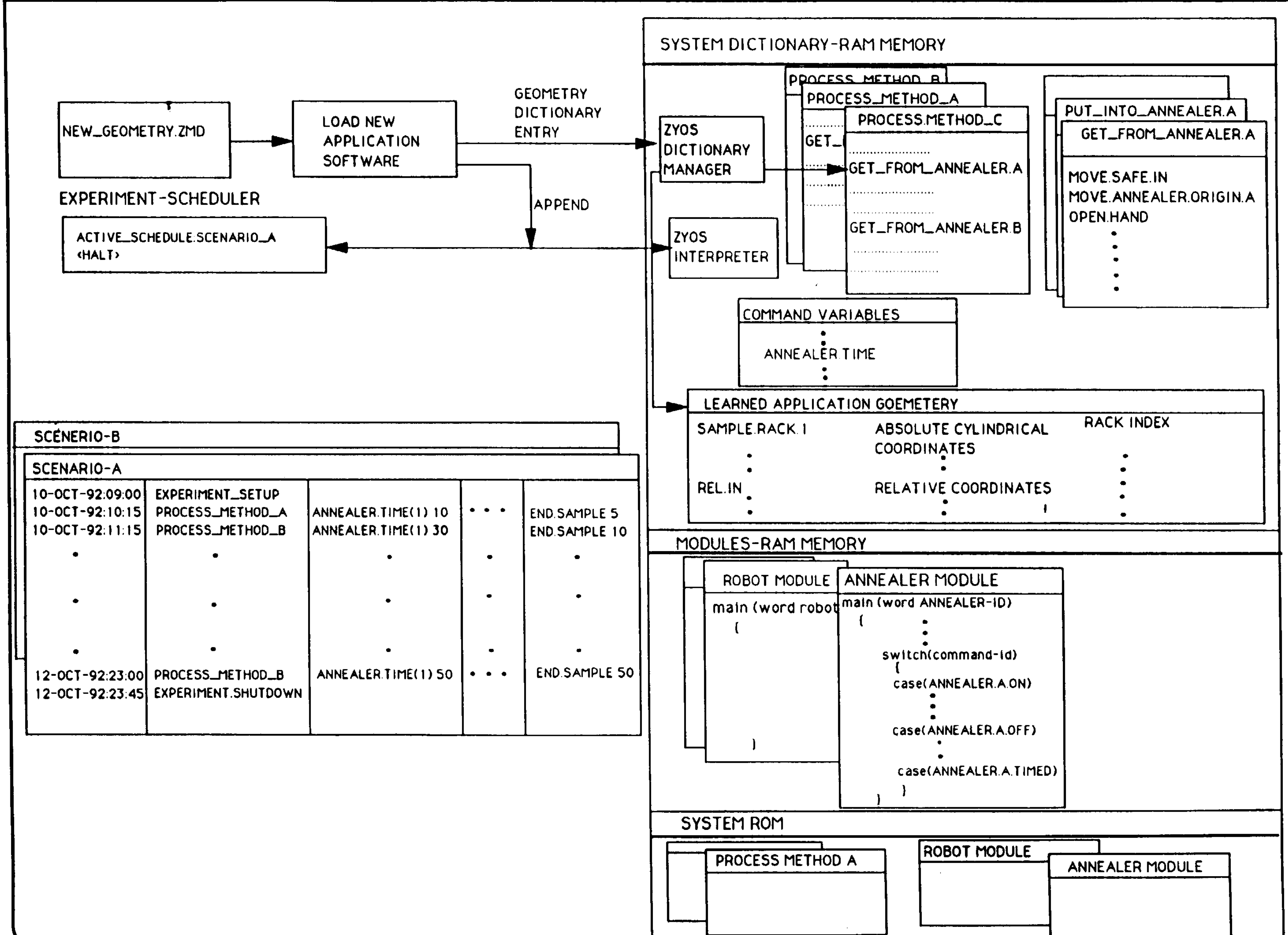
SHUTTLE PROBLEM CAUSE POSTPONEMENT OF OCT-12 EXPERIMENT



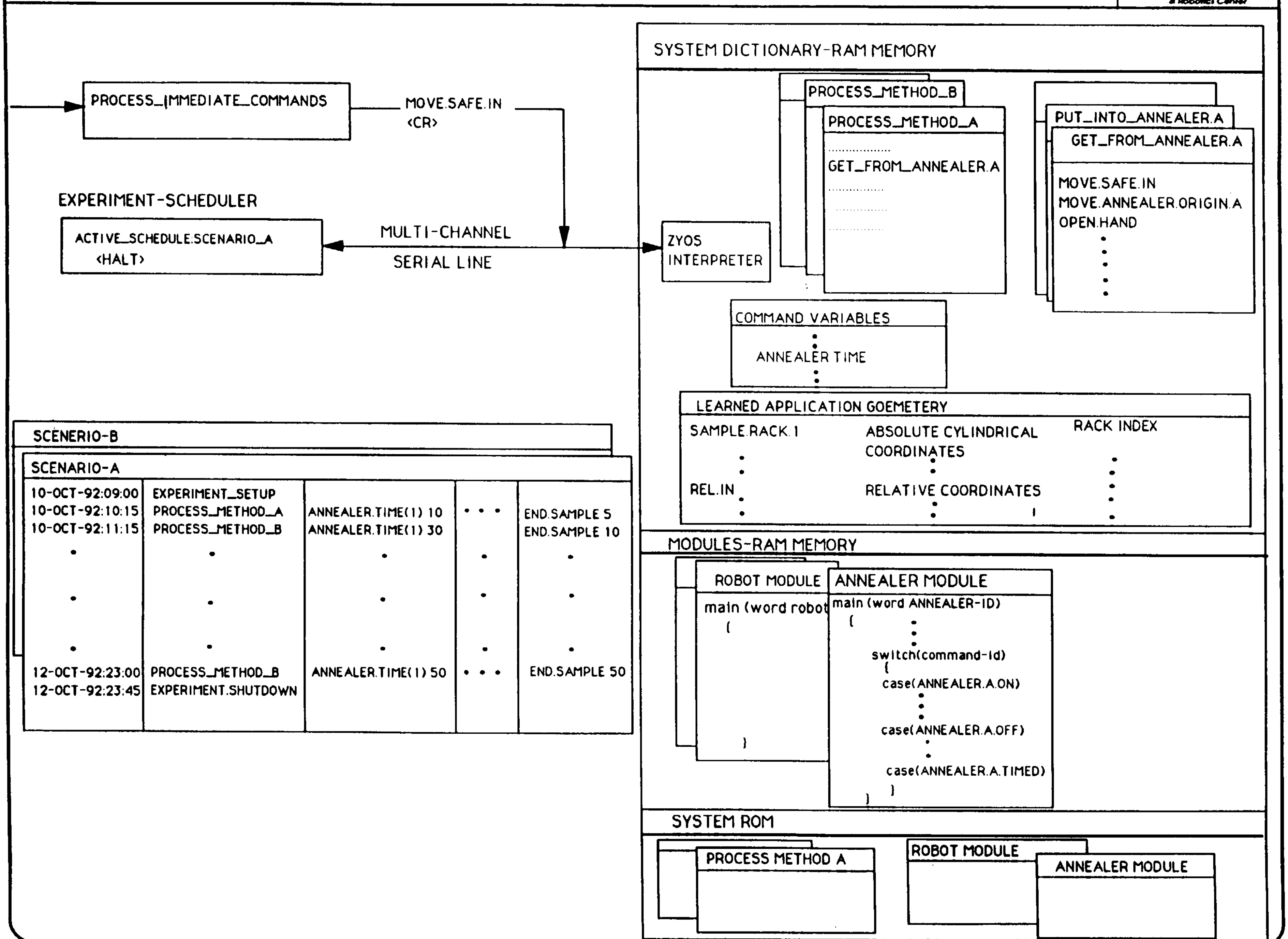
EXPERIMENTERS DISCOVER ANOMALIES BETWEEN IDENTICAL SAMPLES PROCESSED IN OVEN A AND OVEN B:
WANT LAST TWO PROCESS RUNS WITH NEW METHOD



ROBOT UNABLE TO GRAB SAMPLES FROM RACK
LOAD NEW APPLICATION GOEMETRY



SINGLE STEP IMMEDIATE COMMAND MODE



```
May 12 19:48 1991  process_method_a.zy Page 1

- EasyLabsyLab program PROCESS_METHOD_A
- This procedure processes a samples START.SAMPLE to END.SAMPLE,
- using annealing oven a and the processing parameters contained in
- ANNEALER.TEMPS and ANNEALER.TIMES.

                - NOTE : WORKING.SAMPLE IS A LOCAL TYPE VARIABLE
                - THE START.SAMPLE IS ASSUMED TO BE SET BY THE CALLING
                - MODULE, THIS METHOD OF PARAMETER PASSING IS USED
                - THROUGHOUT THIS PROGRAM
WORKING.SAMPLE = START.SAMPLE

                - Get the sample to be processed
                - NOTE SAMPLE.RACK.1.INDEX IS USED BY THE ROBOT MODULE
                - TO DETERMINE THE SAMPLE WITHIN A RACK TO GET
SAMPLE.RACK.1.INDEX = WORKING.SAMPLE
GET.FROM.SAMPLE.RACK.1

                - put the sample in the annealer
PUT.INTO.ANNEALER.A

                - Set the temperature and time for the oven
                - and anneal the sample
ANNEALER.A.TEMPERATURE = ANNEALER.TEMPS(WORKING.SAMPLE)
ANNEALER.A.TIME = ANNEALER.TIMES(WORKING.SAMPLE)
ANNEALER.A.TIMED.RUN

                - Get the sample from the annealer
GET.FROM.ANNEALER.A

                - Put the sample into the inspection station
PUT.INTO.INSPECTER

                - Measure the sample
OBTAIN.SAMPLE.PROPERTIES

                - Put Sample back into rack
PUT.INTO.SAMPLE.RACK.1

                - Determine if we have processed all the samples
WORKING.SAMPLE = WORKING.SAMPLE.1
IF WORKING.SAMPLE <= END.SAMPLE THEN 10
```

```
May 12 19:48 1991  process_method_b.zy Page 1

- EasyLabsyLab program PROCESS_METHOD_A
- This procedure processes a samples START.SAMPLE to END.SAMPLE,
- using annealing oven b and the processing parameters contained in
- ANNEALER.TEMPS and ANNEALER.TIMES.

WORKING.SAMPLE = START.SAMPLE

                        - Get the sample to be processed
SAMPLE.RACK.1.INDEX = WORKING.SAMPLE
GET.FROM.SAMPLE.RACK.1

                        - put the sample in the annealer
PUT.INTO.ANNEALER.B

                        - Set the temperature and time for the oven
                        - and anneal the sample
ANNEALER.B.TEMPERATURE = ANNEALER.TEMPS(WORKING.SAMPLE)
ANNEALER.B.TIME = ANNEALER.TIMES(WORKING.SAMPLE)
ANNEALER.B.TIMED.RUN

                        - Get the sample from the annealer
GET.FROM.ANNEALER.B

                        - Put the sample into the inspection station
PUT.INTO.INSPECTER

                        - Measure the sample
OBTAIN.SAMPLE.PROPERTIES

                        - Put Sample back into rack
PUT.INTO.SAMPLE.RACK.1

                        - Determine if we have processed all the samples
WORKING.SAMPLE = WORKING.SAMPLE.1
IF WORKING.SAMPLE <= END.SAMPLE THEN 10
```

```
- EasyLabsyLab program PROCESS_METHOD_C
- This procedure processes a samples START.SAMPLE to END.SAMPLE,
- using annealing oven a and the processing parameters contained in
- ANNEALER.TEMPS and ANNEALER.TIMES. It processes the sample a second
- time using the same processing parameters but using oven b.

                - This start the processing at the desired sample
WORKING.SAMPLE = START.SAMPLE

                - Get the sample to be processed
SAMPLE.RACK.1.INDEX = WORKING.SAMPLE
GET.FROM.SAMPLE.RACK.1

                - put the sample in the annealer
PUT.INTO.ANNEALER.A

                - Set the temperature and time for the oven
                - and anneal the sample
ANNEALER.A.TEMPERATURE = ANNEALER.TEMPS(WORKING.SAMPLE)
ANNEALER.A.TIME = ANNEALER.TIMES(WORKING.SAMPLE)
ANNEALER.A.TIMED.RUN

                - Get the sample from the annealer
GET.FROM.ANNEALER.A

                - Put the sample into the inspection station
PUT.INTO.INSPECTER

                - Measure the sample
OBTAIN.SAMPLE.PROPERTIES

                - put the sample in the annealer
PUT.INTO.ANNEALER.B

                - Set the temperature and time for the oven
                - and anneal the sample
ANNEALER.B.TEMPERATURE = ANNEALER.TEMPS(WORKING.SAMPLE)
ANNEALER.B.TIME = ANNEALER.TIMES(WORKING.SAMPLE)
ANNEALER.B.TIMED.RUN
```

May 12 19:43 1991 process_method_c.zy Page 2

```
                    - Get the sample from the annealer
GET.FROM.ANNEALER.B

                    - Put the sample into the inspection station
PUT.INTO.INSPECTER

                    - Measure the sample
OBTAIN.SAMPLE.PROPERTIES

                    - Put Sample back into rack
PUT.INTO.SAMPLE.RACK.1

                    - Determine if we have processed all the samples
WORKING.SAMPLE = WORKING.SAMPLE.1
IF WORKING.SAMPLE <= END.SAMPLE THEN 10
```

Hitchhiker Interface Requirements

Robot TM for static conditions

Power TM yields Dynamics via 15 Hz current sig

which can be monitored for study purposes

3 CPU param –

Retain full dynamic ... Configuration → ROBOT [illegible]

Could be ported to UNIX environment but

would lose support

GSE – health & safety

– Limits

– "[illegible]" "[illegible]"

Hitchiker Avionics Interface Requirements
Summary

Bilevel Commands (+28V)

- bus A/B select
- oven enable
- processor restart
- system halt

Serial Command

- NONE

Asyncronous Uplink (RD)

- 1200 baud (1 start, 8 data, no parity, 1 stop)
- customer message - basic functions
  - operating system commands
  - experiment commands
- volume
  - TBD Bytes/Hour
- mission elapsed time (asyncronous or syncronous)

Asyncronous Downlink (SD)

- 1200 baud (1 start, 8 data, no parity, 1 stop)
- customer data - basic content
  - operating system status
  - experiment status
- volume
  - TBD Bytes/Hour

Medium Rate Downlink

- NONE

PCM Telemetry

- NONE

Analog Data

- Experiment Total Current

Temperature Data

- SEA Baseplate
- GAS Structure
- GAS Heatsink

IRIG-B MET

- None

1 Minute Pulse

- None

Hitchiker Avionics Interface Requirements
Telemetry Format
1 Second Frame

Mnemonic	Description	Type	Len	Range
SYNC	sync	byte	8	
SYNC	sync	byte	8	
SYNC	sync	byte	8	
ID	frame identifcation	byte	8	
SEC	sec	byte	8	0-59
MIN	min	byte	8	0-59
HOUR	hour	byte	8	0-11
UDAY	1's day	byte	8	0-9
TDAY	10's day	byte	8	0-3
	Manufacturing Control			
SLINE	schedule line number	byte	8	0-255
EXPID	experiment id	byte	8	0-255
ELINE	experiment line number	byte	8	0-255
SAMP	sample number	byte	8	0-255
	Manufacturing Process			
	pyrometer output	intg	16	
	sample temp	real	16	
	lamp intensity	real	16	
	lamp current	real	16	
	lamp voltage	real	16	
	Manufacturing Data			
	characterization output 1	real	16	
	characterization output 2	real	16	
	characterization output 3	real	16	
	characterization output 4	real	16	
	Robot Status			
	Z position	intg	16	
	Theta position	intg	16	
	Radial position	intg	16	
	Gripper position	intg	16	
	Radial force	real	16	
	Gripper force	real	16	
	Total Bytes			

Hitchiker Avionics Interface Requirements
Telemetry Format
1 Minute Frame

Mnemonic	Description	Type	Len	Range
SYNC	sync	byte	8	
SYNC	sync	byte	8	
SYNC	sync	byte	8	
ID	frame identifcation	byte	8	
	Manufacturing Calibration			
	pyrometer calibration	intg	16	
	pyrometer calibration	intg	16	
	pyrometer calibration	intg	16	
	pyrometer calibration	intg	16	
	Operating System			
OPSTAT	processor status	byte	16	
OSSTAT	software status	byte	16	
	Robot Controller			
CPSTAT	processor status	byte	16	
CSSTAT	software status	byte	16	
	Current Monitors			
ZMIMON	Z motor	real	8	0-tbd amp
TMIMON	Theta motor	real	8	0-tbd
RMIMON	Radial motor	real	8	0-tbd
GMIMON	Gripper motor	real	8	0-tbd
CPU1IMON	processor 1	real	8	0-1
CPU2IMON	processor 2	real	8	0-1
	Temperature Monitors - Support Electronics Assembly			
PWRTMP	power distribution	real	8	-20 +60 °C
CPU1TMP	processor 1	real	8	-20 +60
CPU2TMP	processor 2	real	8	-20 +60
	Temperature Monitors - Get Away Special Container			
BPTMP	baseplate	real	8	-20 +60
RADTMP	radiator	real	8	-20 +60
OV1TMP	lamp 1	real	8	-20 +60
OV2TMP	lamp 2	real	8	-20 +60
ROBTMP	robot	real	8	-20 +60

Total Bytes

Hitchiker Avionics Interface Requirements
Telemetry Format
Alternate 1 Second Frame

Mnemonic	Description	Type	Len	Range
SYNC	sync	byte	8	
SYNC	sync	byte	8	
SYNC	sync	byte	8	
ID	frame identifcation	byte	8	
	Operating System			
OPSTAT	processor status	byte	16	
OSSTAT	software status	byte	16	
	Robot Controller			
CPSTAT	processor status	byte	16	
CSSTAT	software status	byte	16	
	Data Field	byte	16	
	Total Bytes			

Hitchiker Avionics Interface Requirements
Asyncronous Command RD
Customer Message

- RoMPS payload command blocks will require one or more customer message packets.

  Embedded within the HH specified customer message format will be a customer specified, generated and on-orbit processed command block protocol.

- Contents of customer data in customer messages:

  customer protocol bytes
  ASCII Strings (high level experiment language) or Binary Data (processor load)
  terminator

PRELIMINARY

- User Interface Examples:

  The schedule might look like this

DAY	GMT	EXP
1	1300	01
1	1320	02
1	1900	05
2	2000	04

  The contents of Experiment 01 might look like this:

```
WHILE
        N>10 .and. N<=20
DO
        MOVE.SAMPLE.N.OVEN
        PROCESS.N.OVEN.NORMAL
END
ENDWHILE
```

  However, for engineering purposes the language supports the following:

```
MOVE.AXIS.name.position
STEP.axis.dir.distance.rate
```

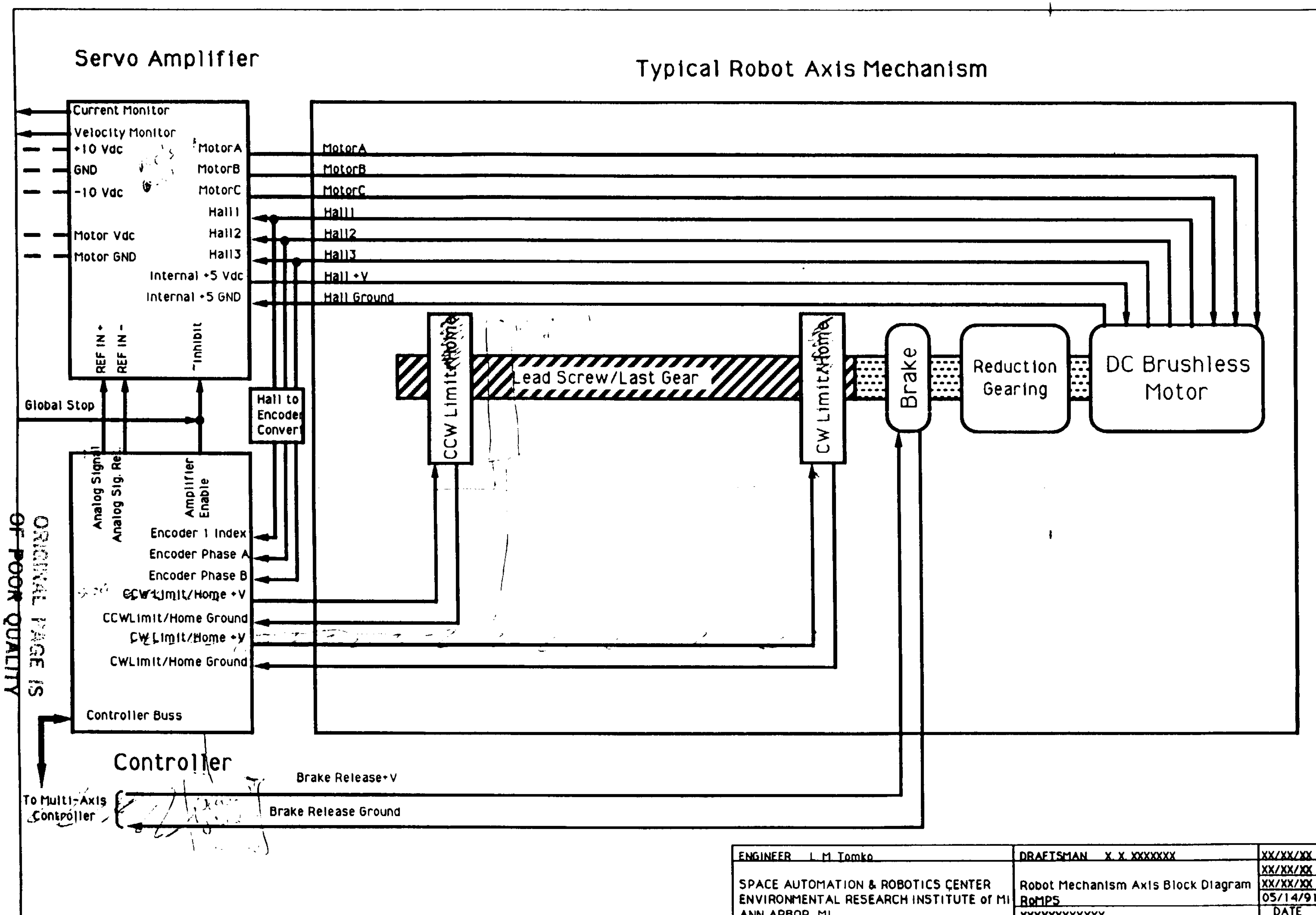
Robot Axis Control Concepts

2C/3D - retain full symmetric compatible
could port to single cpu/unity - plus : minus's.

This one of several implementation option
Purpose is to introduce concept/approval
& proceed to final ~~code~~ selection

req's system design consideration
to minimize change while retaining
real-req'ments

STD BUS, PCAT, VME, ...
INTEL, NEC, 6800X CPU for controller (ease of prgm)
TI for DSP (expensive to prgm)


Servo Amplifier
Typical Robot Axis Mechanism
Current Monitor
Velocity Monitor
+10 Vdc
GND
-10 Vdc
Motor Vdc
Motor GND
MotorA
MotorB
MotorC
Hall1
Hall2
Hall3
Internal +5 Vdc
Internal +5 GND
REF IN +
REF IN -
Inhibit
Global Stop
Hall to Encoder Convert
Hall +V
Hall Ground
CCW Limit/Home
CW Limit/Home
Lead Screw/Last Gear
Brake
Reduction Gearing
DC Brushless Motor
Analog Signal
Analog Sig. Ret
Amplifier Enable
Encoder 1 Index
Encoder Phase A
Encoder Phase B
CCW Limit/Home +V
CCWLimit/Home Ground
CW Limit/Home +V
CWLimit/Home Ground
Controller Buss
Controller
Brake Release+V
Brake Release Ground
To Multi-Axis Controller
ENGINEER L. M. Tomko
DRAFTSMAN X. X. XXXXXXX
SPACE AUTOMATION & ROBOTICS CENTER
ENVIRONMENTAL RESEARCH INSTITUTE of MI
ANN ARBOR, MI
Robot Mechanism Axis Block Diagram
RoMPS
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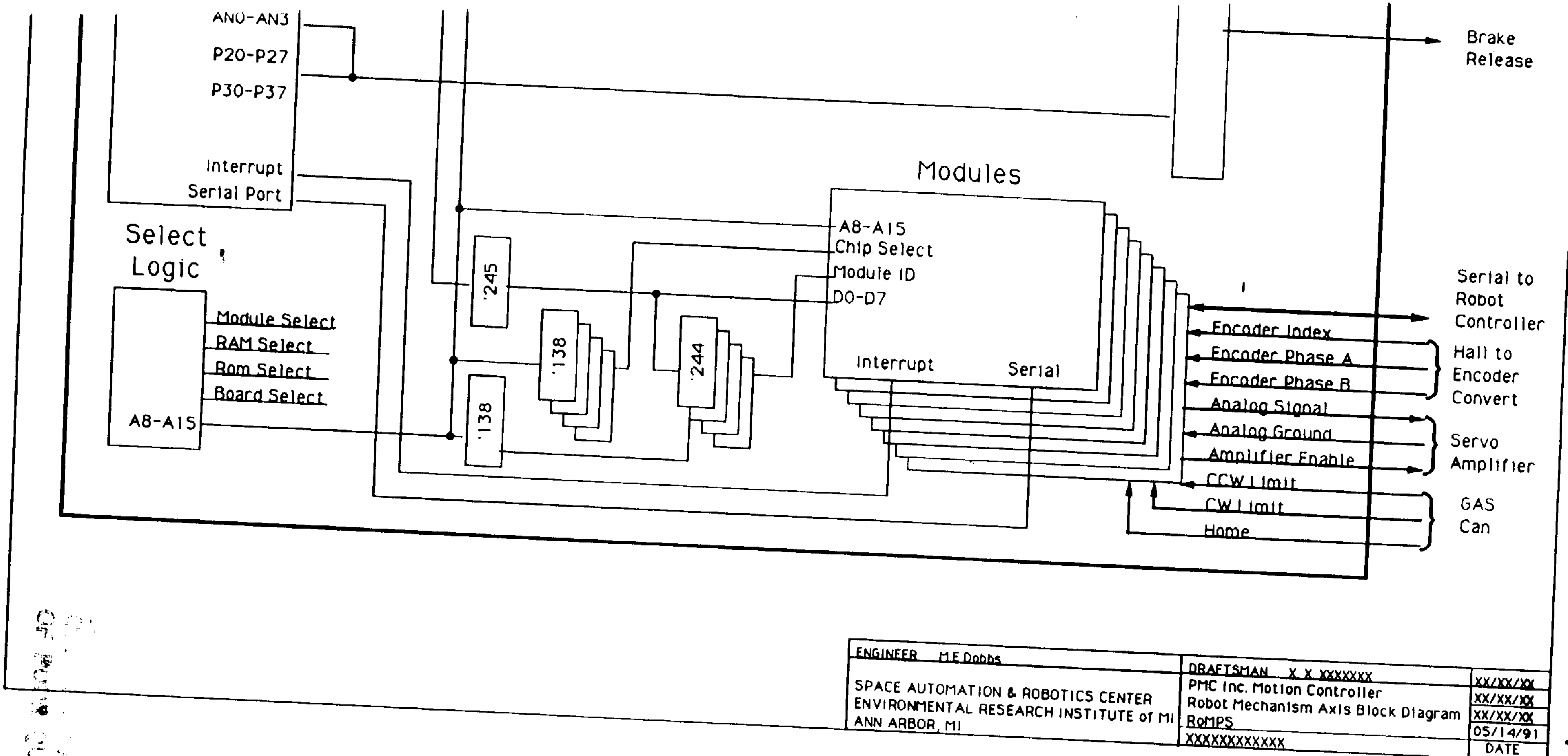


3.1.1

RC	Reset Counter
RT	Reset seT
SA	Set Acceleration
SD	Set Derivative gain
SG	Set prop. Gain of motor
SI	Set Integral gain of DC servo or
	Set Initial pulse rate of stepper
SQ	Set torQue
SV	Set Velocity
VG	Set Velocity Gain

Sequence Commands

IP	Interrupt on absolute Position
IR	Interrupt on Relative position
RP	RePeat
WA	Wait (time)
WE	Wait for Edge
WP	Wait for absolute Position
WR	Wait for Relative position
WS	Wait for Stop

SpARC 051491/ME1.0

Register Command

AA	Accumulator Add
AC	Accumulator Complement, blt wise
AE	Accumulator logical Exclusive or with *n*, bit wise
AI	Accumulator load Indirect
AL	Accumulator Load with constant *n*
AN	Accumulator logical aNd with *n*, bit wise
AO	Accumulator logical Or with *n*, bit wise
AR	copy Accumulator to Register *n*
AS	Accumulator Subtract
RB	Read Byte
RL	Read Long at absolute memory location *n* into accumulator
RW	Read Word at absolute memory location *n* into accumulator
SL	Shift Left -accumulator *n* bits
SR	Shlft Right accumulator *n* bits
TR	Tell contents of Register *n*
	Tell contents of accumulator (register O)
WB	Wrlte accumulator low Byte to absolute memory location *n*
WL	Write accumulator Long to absolute memory location *n*
WW	Write accumulator low Word to absolute memory location *n*

Learn Mode Commands

AP	Adjust Position
LI	Learn position Incrementing
LP	Learn Position
LT	Learn Target
MI	Move to point, Incrementing
MP	Move to Point

Reporting Commands

CC	Current Count
CS	Check Sum
HE	HElp
TA	Tell Analog to digital converter
TD	Tell Derivative qain
TF	Tell Following error
TG	Tell position Gain
TI	Tell Integral gain of DC servo or Tell Initial pulse rate of stepper
TL	Tell Integration Limit
TP	Tell Position
TS	Tell Status
TT	Tell Target
TV	Tell Velocity
VE	Tell VErsion

Macro Commands

EM	Execute Macro
MC	Macro Command
MD	Macro Definition
RM	Reset Macros
TM	Tell Macros

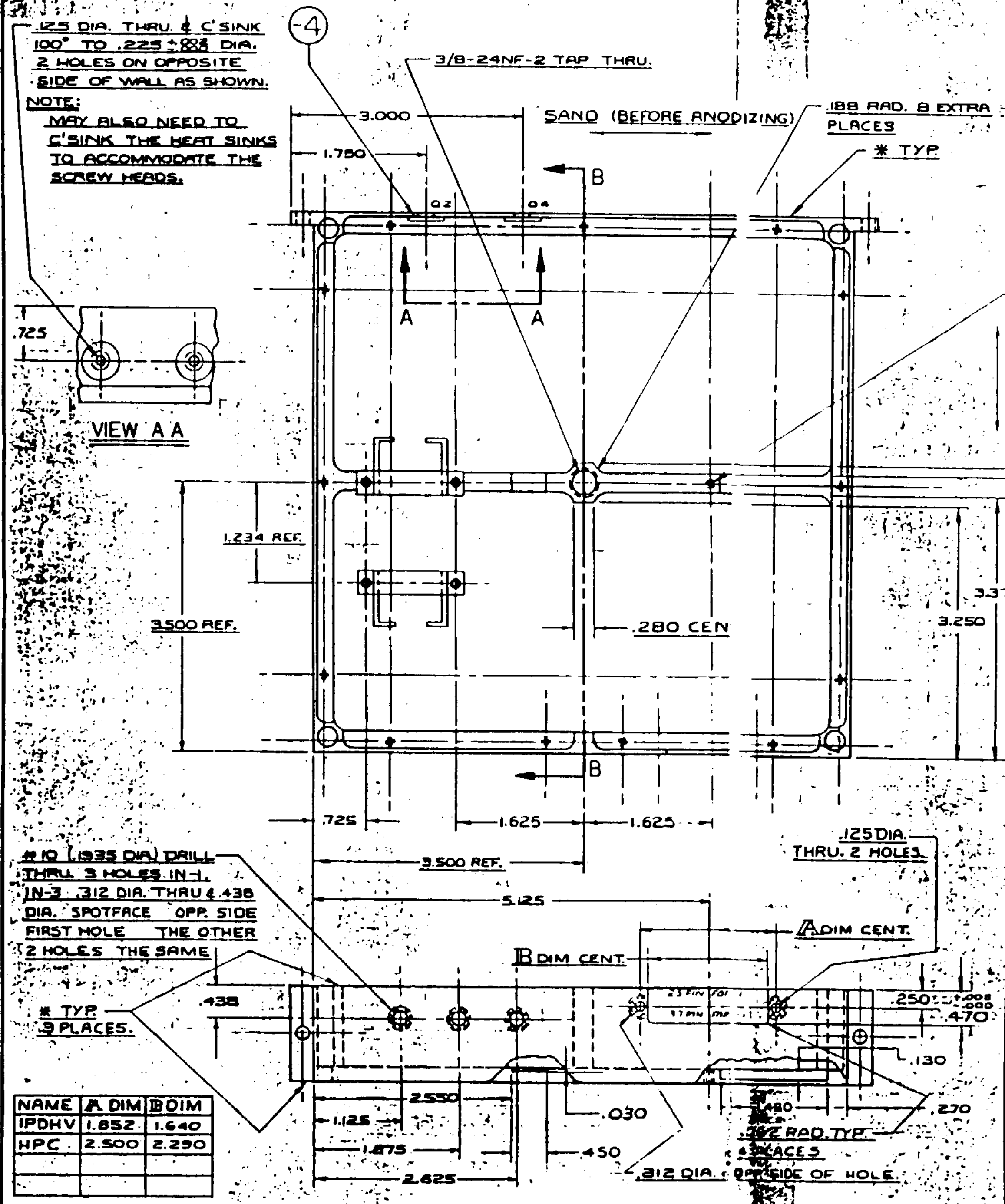
Contouring Mode Commands

CM	Contouring Mode

Miscellaneous Commands

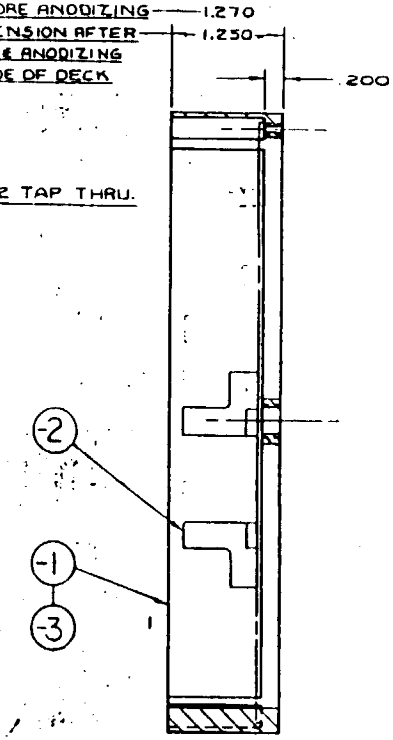
BK	BreaK
DM	Decimal Mode
HM	Hexidecimal Mode
NO	No Operation
SB	Select Bank

ZONE	LTR	REVISION DESCRIPTION	DFTMN	DATE	APP.
		DESIGN CONTROLLED	C.C.Z	1-27-86	HJG
		SEE ECN	C.C.Z	4-7-86	HJG MED
	A	SEE ECN	C.C.Z	1-27-87	HJG JDS
	B	ADDED .312 HOLE TO -3	LSG	3.28.87	



NAME	A DIM	B DIM
IPDHV	1.852	1.640
HPC	2.500	2.290

DIMENSION BEFORE ANODIZING — 1.270
FINISHED DIMENSION AFTER REMOVING .010 & ANODIZING FROM EACH SIDE OF DECK — 1.250



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2476

NOTES:

1. TO BE USED WITH AND AS PART OF DWG.* D-038-305. (THIS IS A 1¼" DECK.) USE CERTIFIED STOCK.
2. ALL EXTERIOR SURFACES TO BE SANDED WITH ABRASIVE PAPER (GRAIN SIZE 320 AS SHOWN.)
3. BREAK ALL SHARP EDGES.
4. BLACK ANODIZE MIL-A-8625C, TYPE II, CLASS 2.
5. REMOVE ANODIZING FROM THOSE SURFACES AS MARKED ▩ OR POINTED TO *. (.010 TO BE REMOVED FROM TOP AND BOTTOM OF DECK AFTER ANODIZING)

L.R.	S.R.	PART NO.	L.R.	D.N.	NAME	SIZE	MATERIAL / DESCRIPTION
2		B-038-390		-4	INS. WASHER FOR Q2 & Q4		FOR BOTH DECKS
1				-3	HPC	1.270 × 7.000 × 7.625 REF.	6061-T651 AL
2		B-038-319		-2	BRACKET		FOR BOTH DECKS
1				-1	IPDHV	1.270 × 7.000 × 7.625 REF.	6061-T651 AL

SPACE PHYSICS RESEARCH LABORATORY
COLLEGE OF ENGINEERING
THE UNIVERSITY OF MICHIGAN
ANN ARBOR, MICHIGAN

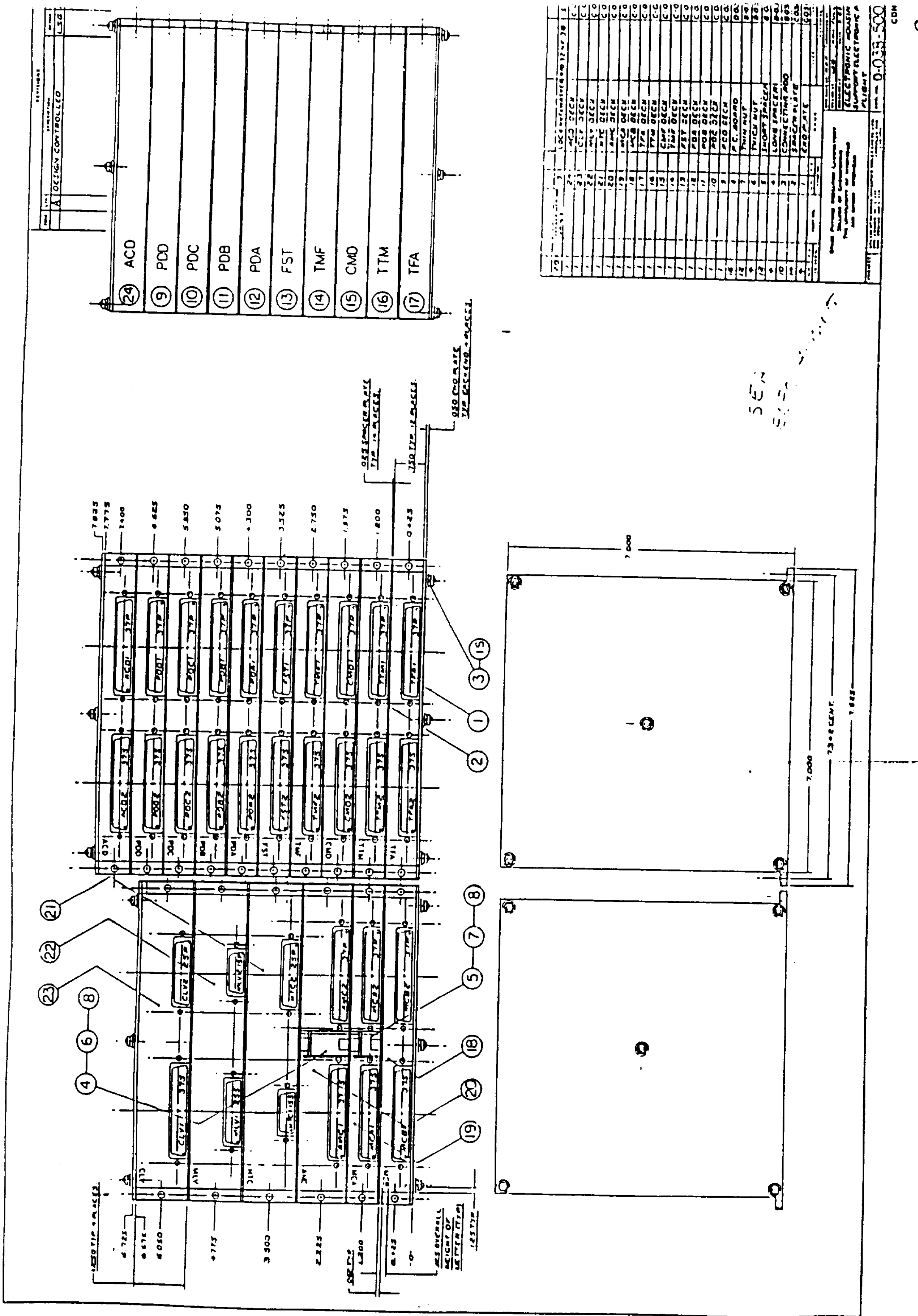
DESIGNED BY B.J.C. | DRAWN BY J. MITCHELL | CHECKED BY B.J.C. | SCALE FULL SIZE | DATE 6-7-85

IPDHV DECK & HPC DECK ELECTRONIC HOUSING ASS'Y. FLIGHT HRDT

UNLESS OTHERWISE SPECIFIED TOLERANCES ARE: DIM. ENDING IN .XXX ±.005 ANGULAR DIM. ±.30 MIN.

DWG. NO. C-038-306 B

CONTROLLED



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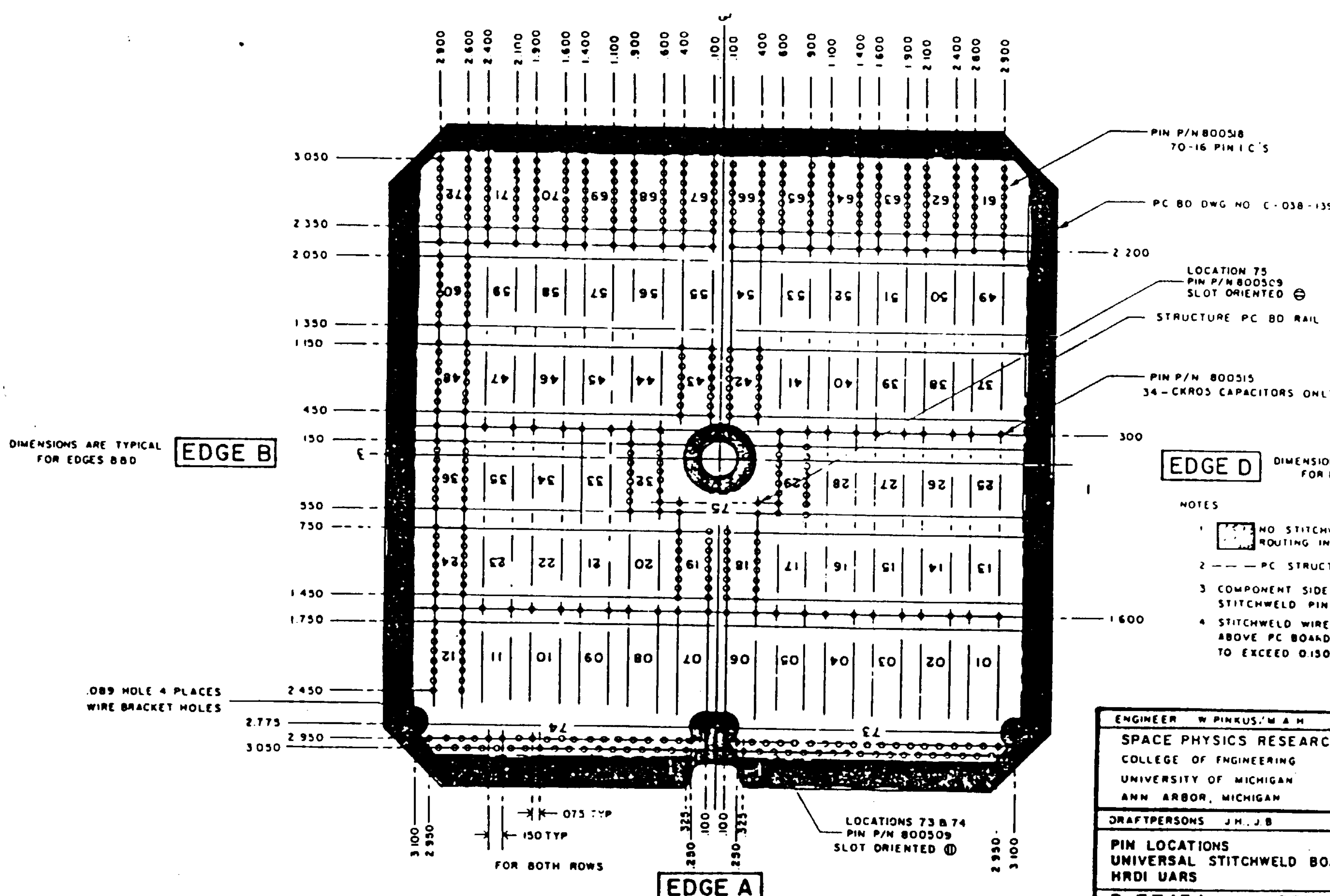

EDGE D

DIMENSIONS ARE TYPICAL FOR EDGES B&D

NOTES

1. NO STITCHWELD WIRE ROUTING IN THESE AREAS
2. — — — PC STRUCTURE RAIL LIMIT
3. COMPONENT SIDE VIEW OF PC BD STITCHWELD PIN LOCATIONS.
4. STITCHWELD WIRE BUNDLE HEIGHT ABOVE PC BOARD SURFACE NOT TO EXCEED 0.150.

ENGINEER W PINKUS/M A H	
SPACE PHYSICS RESEARCH LABORATORY COLLEGE OF ENGINEERING UNIVERSITY OF MICHIGAN ANN ARBOR, MICHIGAN	
DRAFTPERSONS J.H., J.B	4/12/8
PIN LOCATIONS UNIVERSAL STITCHWELD BOARD HRDI UARS	10/6/
B-E7434 CONTROLLED	DA

9

ORIGINAL PAGE IS
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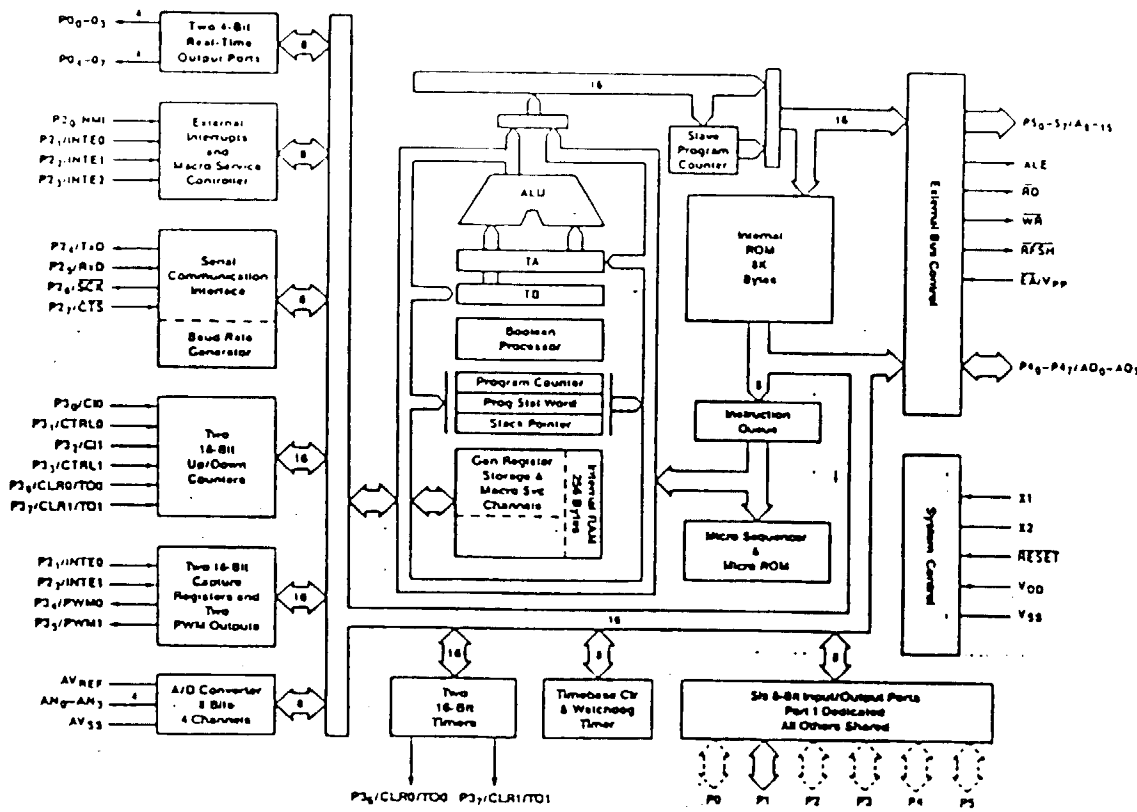
NEC μPD7831xA 16-Bit Single-chip Microcomputer for Real-Time Control

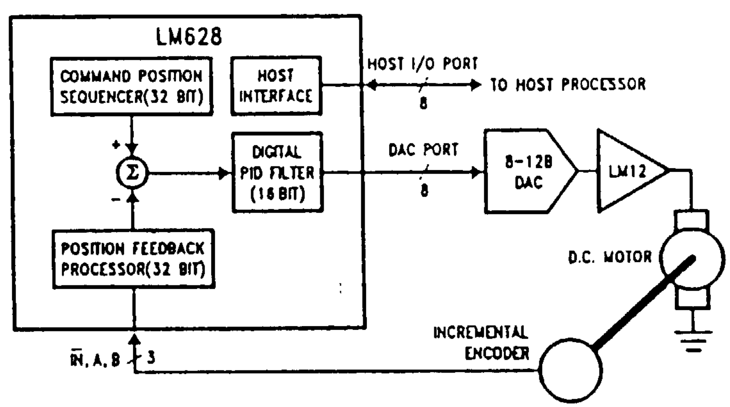
Features

- Complete single-chip microcomputer
  - 16-bit ALU
  - 8K ROM (μPD78312A only)
  - 256 bytes RAM
  - 1-bit and 8-bit logic
- Instruction prefetch queue
- 16-bit unsigned multiply and divide
- String instructions
- Memory expansion
  - 8085A bus-compatible
  - Total 64K address space
- Large I/O capacity: up to 32 I/O port lines
- Extensive timer/counter system
  - Two 16-bit up/down counters
  - Quadrature counting
  - Two 16-bit timers
  - Free-running counter with two 16-bit capture registers
  - Pulse-width modulated outputs
  - Timebase counter
- Four-channel 8-bit A/D converter
- Two 4-bit real-time output ports
- Two nonmaskable interrupts
- Eight hardware priority interrupt levels
- Macroservice facility for interrupts gives the effect of eight DMA channels
- Bidirectional serial port
  - Either UART or interface mode
  - Dedicated baud rate generator
- Watchdog timer
- Refresh output for pseudostatic RAM
- Programmable HALT and STOP modes
- One-byte call instruction
- On-chip clock generator
- CMOS silicon gate technology
- +5-volt power supply

Block Diagram



ENGINEER M E Dodds	DRAFTSMAN X X XXXXXXX	XX/XX/XX
SPACE AUTOMATION & ROBOTICS CENTER ENVIRONMENTAL RESEARCH INSTITUTE of MI ANN ARBOR, MI	NEC uPD7831xA 16-bit microcontrolle	XX/XX/XX
	Robot Mechanism Axis Block Diagram	XX/XX/XX
	RoMPS	05/14/91
	XXXXXXXXXXXX	DATE



TL/H/9219-1

FIGURE 1. Typical System Block Diagram

Features

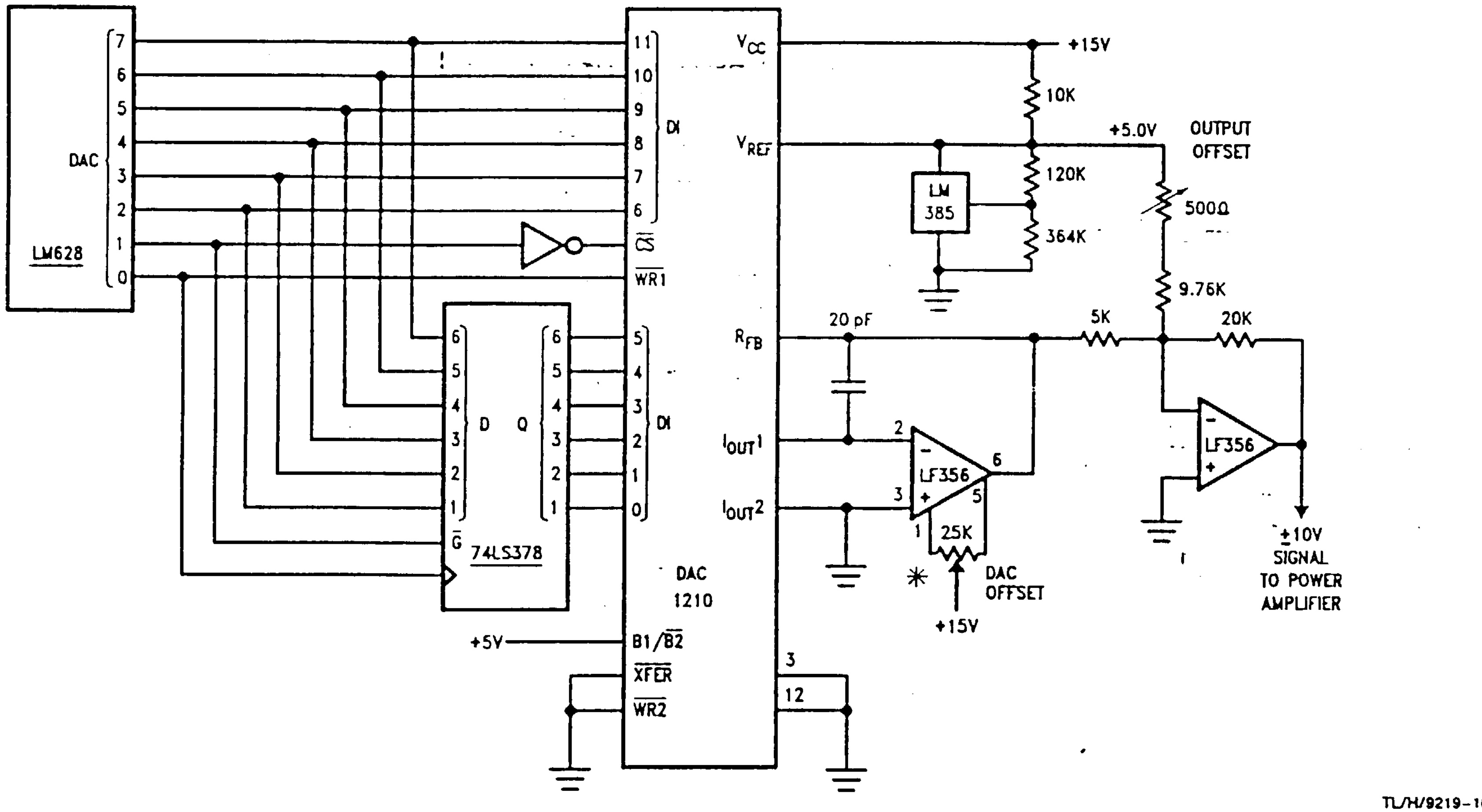
- 32-bit position, velocity, and acceleration registers
- Programmable digital PID filter with 16-bit coefficients
- Programmable derivative sampling interval
- 8- or 12-bit DAC output data (LM628)
- 8-bit sign-magnitude PWM output data (LM629)
- Internal trapezoidal velocity profile generator
- Velocity, target position, and filter parameters may be changed during motion
- Position and velocity modes of operation
- Real-time programmable host interrupts
- 8-bit parallel asynchronous host interface
- Quadrature incremental encoder interface with index pulse input

ENGINEER M.E.Dobbs	DRAFTSMAN X. X. XXXXXXX	XX/XX/XX
SPACE AUTOMATION & ROBOTICS CENTER	LM628629 Motion Controller IC (MC100 system)	XX/XX/XX
ENVIRONMENTAL RESEARCH INSTITUTE of MI	Robot Mechanism Axis Block Diagram	XX/XX/XX
ANN ARBOR, MI	RoMPS	05/14/91
	XXXXXXXXXXXX	DATE

TABLE I. System Specifications Summary

Position Range	−1,073,741,824 to 1,073,741,823 counts
Velocity Range	0 to 1,073,741,823/2^{16} counts/sample; ie, 0 to 16,383 counts/sample, with a resolution of 1/2^{16} counts/sample
Acceleration Range	0 to 1,073,741,823/2^{16} counts/sample/sample; ie, 0 to 16,383 counts/sample/sample, with a resolution of 1/2^{16} counts/sample/sample
Motor Drive Output	LM628: 8-bit parallel output to DAC, or 12-bit multiplexed output to DAC LM629: 8-bit PWM sign/magnitude signals
Operating Modes	Position and Velocity
Feedback Device	Incremental Encoder (quadrature signals; support for index pulse)
Control Algorithm	Proportional Integral Derivative (PID) (plus programmable integration limit)
Sample Intervals	Derivative Term: Programmable from 2048/f_{CLK} to (2048 * 256)/f_{CLK} in steps of 2048/f_{CLK} (256 to 65,536 μs for an 8.0 MHz clock). Proportional and Integral: 2048/f_{CLK}

ENGINEER M.E.Dobbs	DRAFTSMAN X. X. XXXXXXX	XX/XX/XX
	LM628 Spec Summary	XX/XX/XX
SPACE AUTOMATION & ROBOTICS CENTER	Robot Mechanism Axis Block Diagram	XX/XX/XX
ENVIRONMENTAL RESEARCH INSTITUTE of MI	RoMPS	05/14/91
ANN ARBOR, MI	XXXXXXXXXXXX	DATE



*DAC offset must be adjusted to minimize DAC linearity and monotonicity errors. See text.

FIGURE 14. Interfacing a 12-Bit DAC and LM628

ENGINEER M.E Dobbs	DRAFTSMAN X. X. XXXXXXX	XX/XX/XX
SPACE AUTOMATION & ROBOTICS CENTER	LM628 Analog Application	XX/XX/XX
ENVIRONMENTAL RESEARCH INSTITUTE of MI	Robot Mechanism Axis Block Diagram	XX/XX/XX
ANN ARBOR, MI	RoMPS	05/14/91
	XXXXXXXXXXXX	DATE

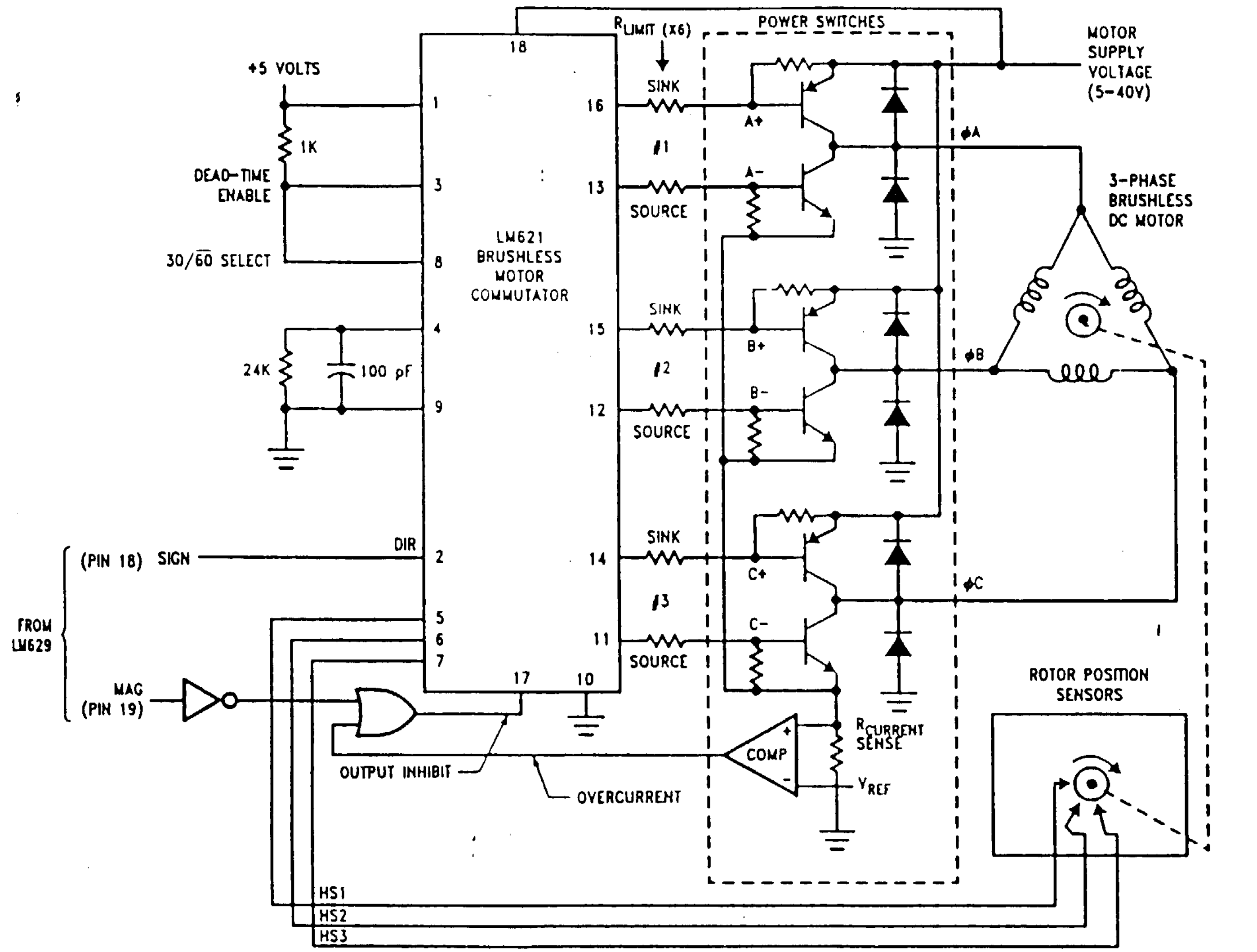
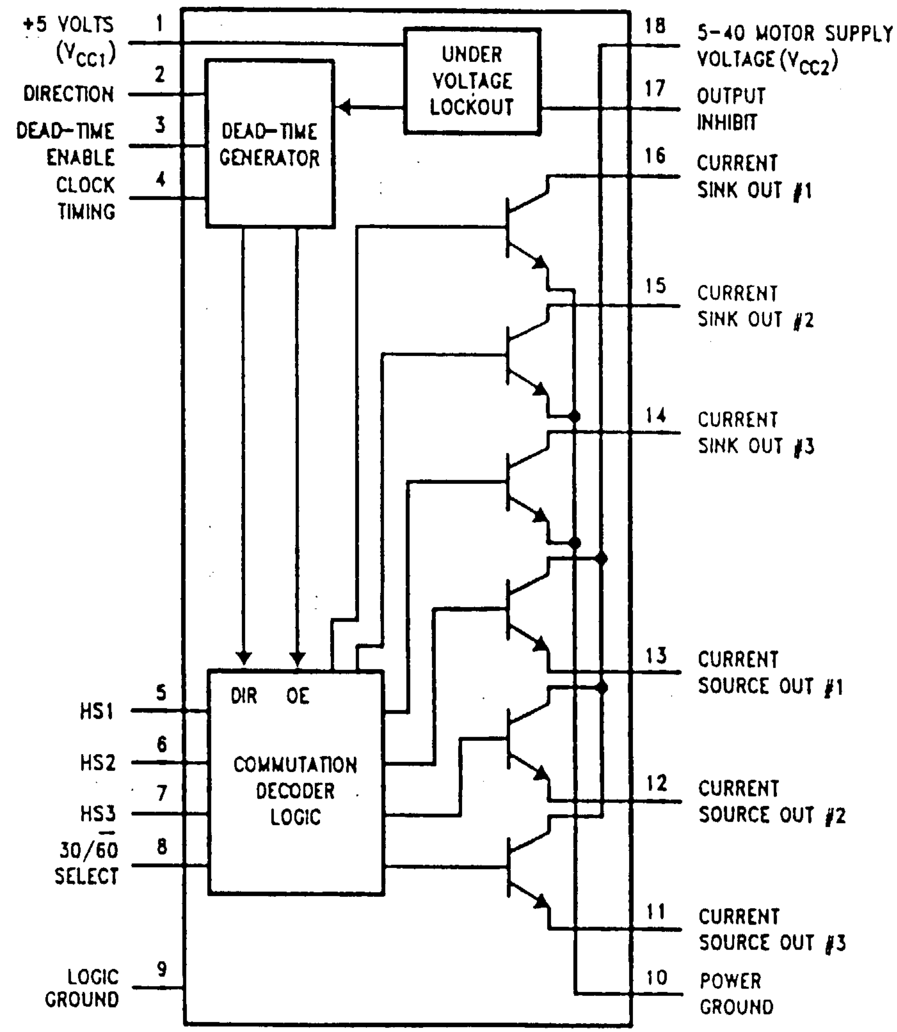


FIGURE 17. PWM Drive for Brushless Motors

ENGINEER M.E.Dobbs	DRAFTSMAN X. X. XXXXXXX	XX/XX/XX
SPACE AUTOMATION & ROBOTICS CENTER	LM629 PWM Application	XX/XX/XX
ENVIRONMENTAL RESEARCH INSTITUTE of MI	Robot Mechanism Axis Block Diagram	XX/XX/XX
ANN ARBOR, MI	RoMPS	05/14/91
	XXXXXXXXXXXX	DATE

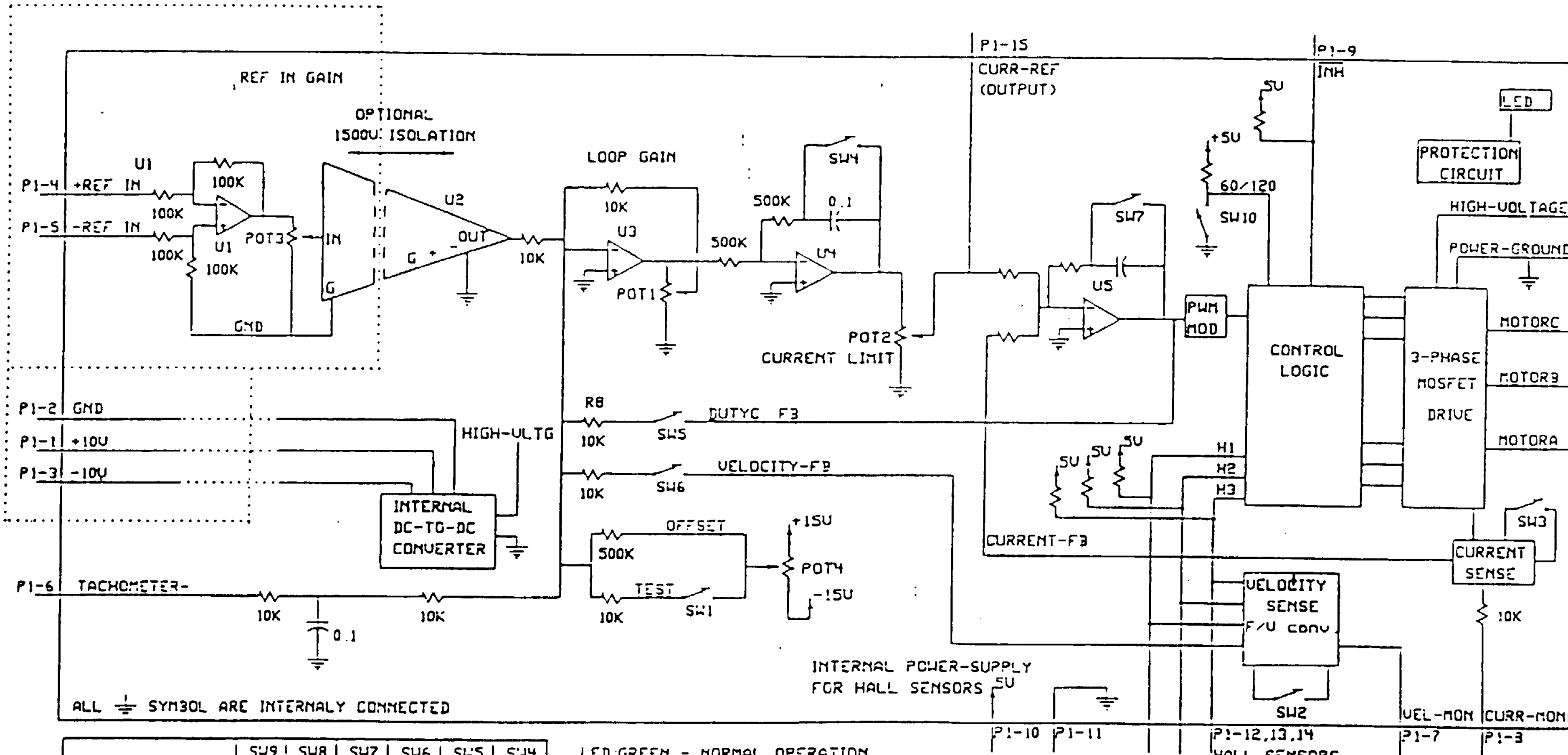
Connection Diagram



TL/H/8679-1

Order Number LM621N
See NS Package Number N18A

ENGINEER M E Dodds	DRAFTSMAN X. X. XXXXXXX	XX/XX/XX
	LM621 Brushless Motor Drive IC	XX/XX/XX
SPACE AUTOMATION & ROBOTICS CENTER	Robot Mechanism Axis Block Diagram	XX/XX/XX
ENVIRONMENTAL RESEARCH INSTITUTE of MI	RoMPS	05/14/91
ANN ARBOR, MI	XXXXXXXXXXXX	DATE



	SW9	SW8	SW7	SW6	SW5	SW4
CURRENT MODE	ON	ON	OFF	OFF	OFF	ON
VELOCITY MODE	OFF	OFF	ON	ON	OFF	*
OPEN LOOP CONTR	ON	ON	OFF	OFF	ON	*

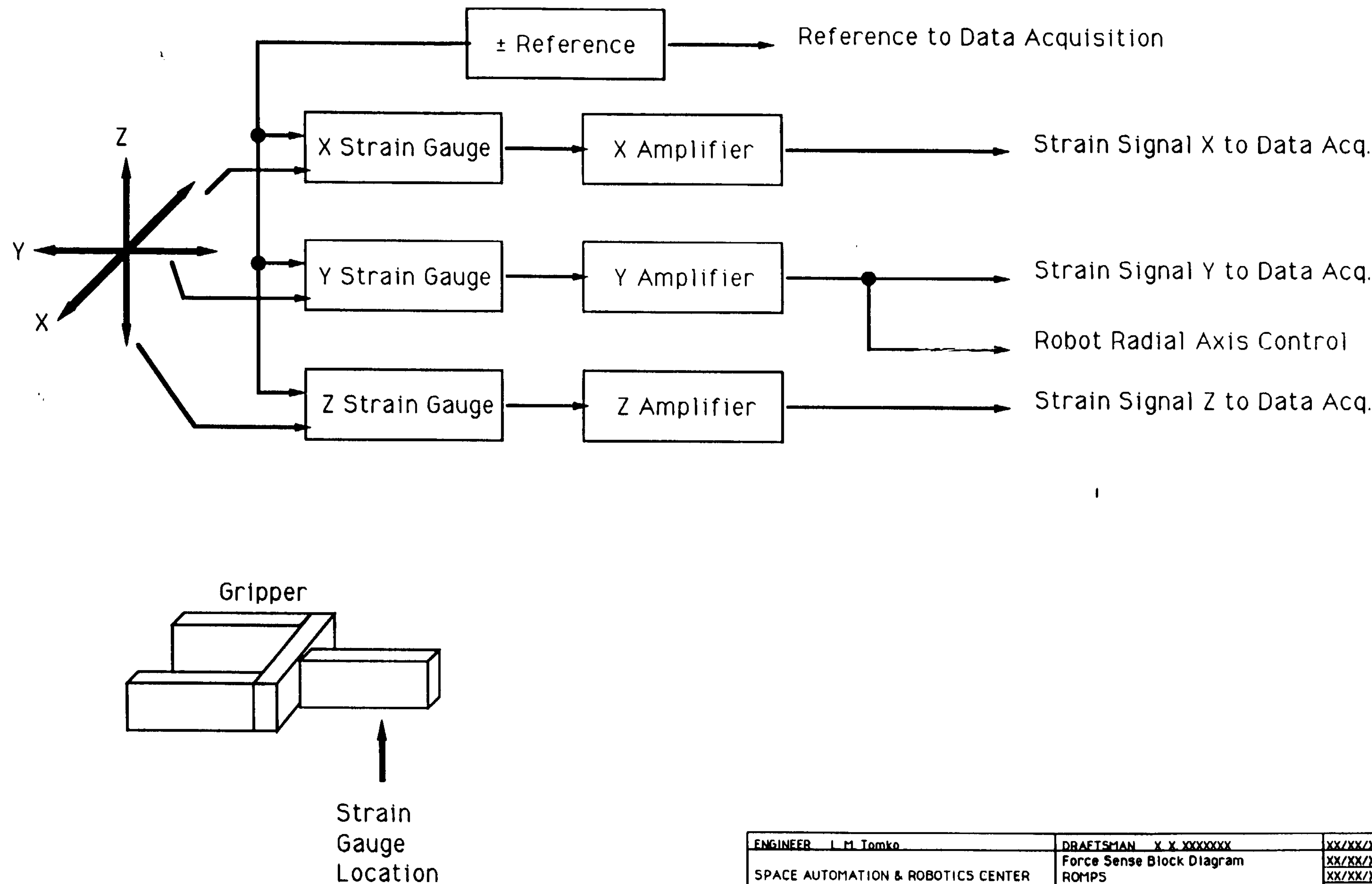
* - DEPENDS ON LOOP COMPENSATION

LED: GREEN - NORMAL OPERATION
RED - FAULT

SW1: ON - POT1 TEST INPUT
OFF - POT1 OFFSET ADJUSTMENT

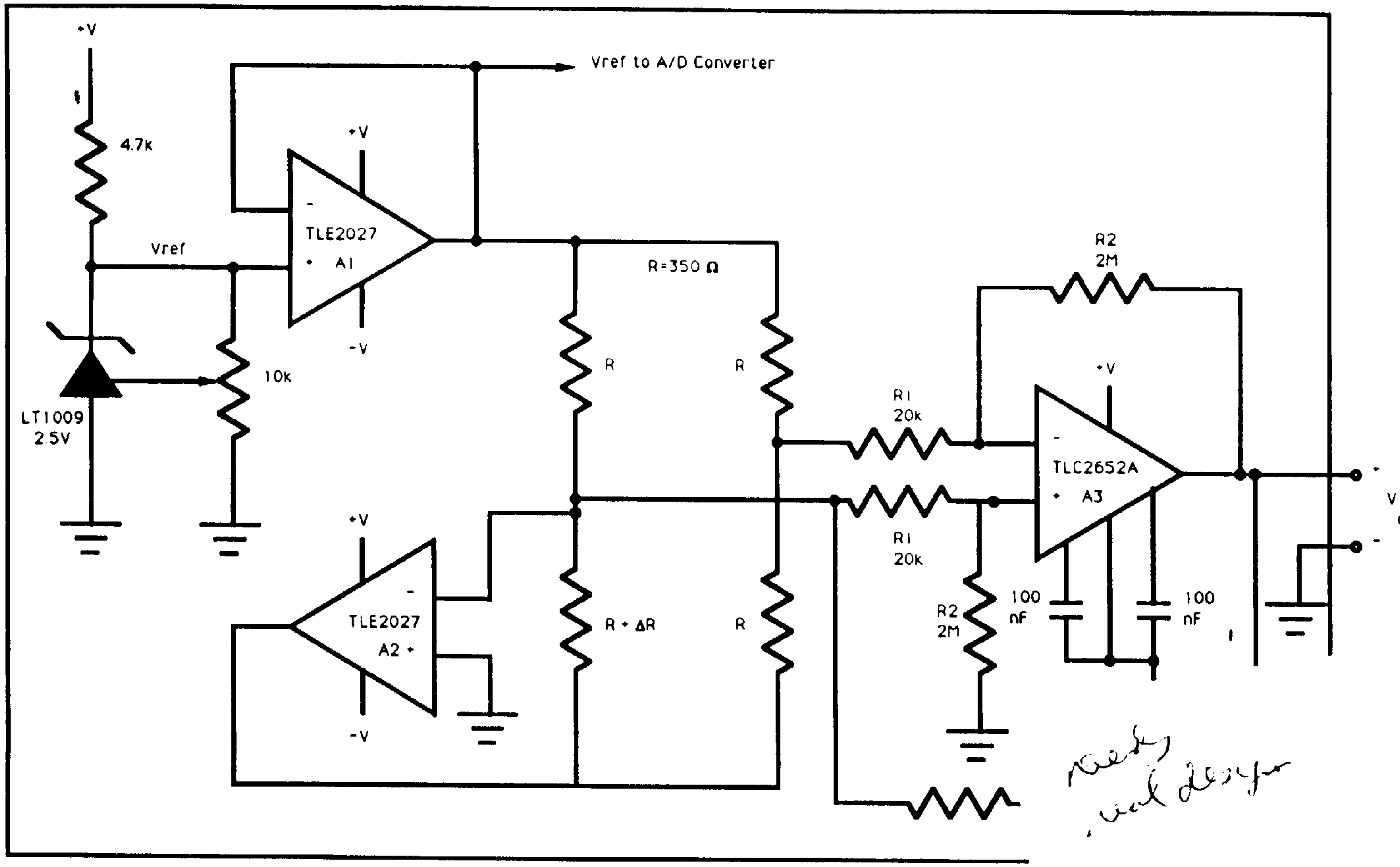
SW10: ON - 120 DEGREE PHASING
OFF - 60 DEGREE PHASING

ENGINEER M.E.Dobbs	DRAFTSMAN X. X. XXXXXXX	XX/XX/XX
SPACE AUTOMATION & ROBOTICS CENTER	AMC Inc. Servo Apmlifier	XX/XX/XX
ENVIRONMENTAL RESEARCH INSTITUTE of MI	Robot Mechanism Axis Block Diagram	XX/XX/XX
ANN ARBOR, MI	RoMPS	05/14/91
	XXXXXXXXXXXX	DATE



ENGINEER L. M. Tomko	DRAFTSMAN X. X. XXXXXXX	XX/XX/XX
	Force Sense Block Diagram	XX/XX/XX
SPACE AUTOMATION & ROBOTICS CENTER	ROMPS	XX/XX/XX
ENVIRONMENTAL RESEARCH INSTITUTE of MI	XXXXXXXXXXXX	05/14/91
ANN ARBOR, MI		DATE

Typical Robot Axis Strain Gauge Amplifier



Very Linear, low noise strain gauge circuit.

The four strain gauge elements (R) and the amplifiers A1 and A2 form a bridge network. The differential connection between the bridge network and amplifier A3 virtually eliminates the offset errors in A1 and A2. Positive feedback through Rx makes the effective input impedance of A3 greater than 1MΩ. The high impedance is used to reduce amplifier loading effects on the bridge circuit. The effects of both input offset and positive feedback resistance are described by the formulas below.

Effect of Rx: $Vo = +1/2 * R2/R1 * \Delta R/R * Vref(1 - Ra/2R1)^{-1}$, $Ra = \begin{cases} -R & \text{Without } Rx \\ \Delta R & \text{Using } Rx = R2 \end{cases}$

Effect of Vio: $Vo = +1/2 * R2/R1 * \Delta R/R * [Vref + Vio(A1) + Vio(A2)] + [1 + R2/R1]\, Vio(A3)$

ENGINEER L. M. Tomko	DRAFTSMAN X. X. XXXXXXX	XX/XX/XX
SPACE AUTOMATION & ROBOTICS CENTER ENVIRONMENTAL RESEARCH INSTITUTE of MI ANN ARBOR, MI	Force Sensing Amplifier-Typical	XX/XX/XX
	Force Sensing Block Diagram	XX/XX/XX
	RoMPS	05/14/91
	XXXXXXXXXXX	DATE

Autonomous Experiment Managment System

Zymate Robot Controller

Southwest SC-4 Computer

Scheduler req'd for autonomous/prod. environment

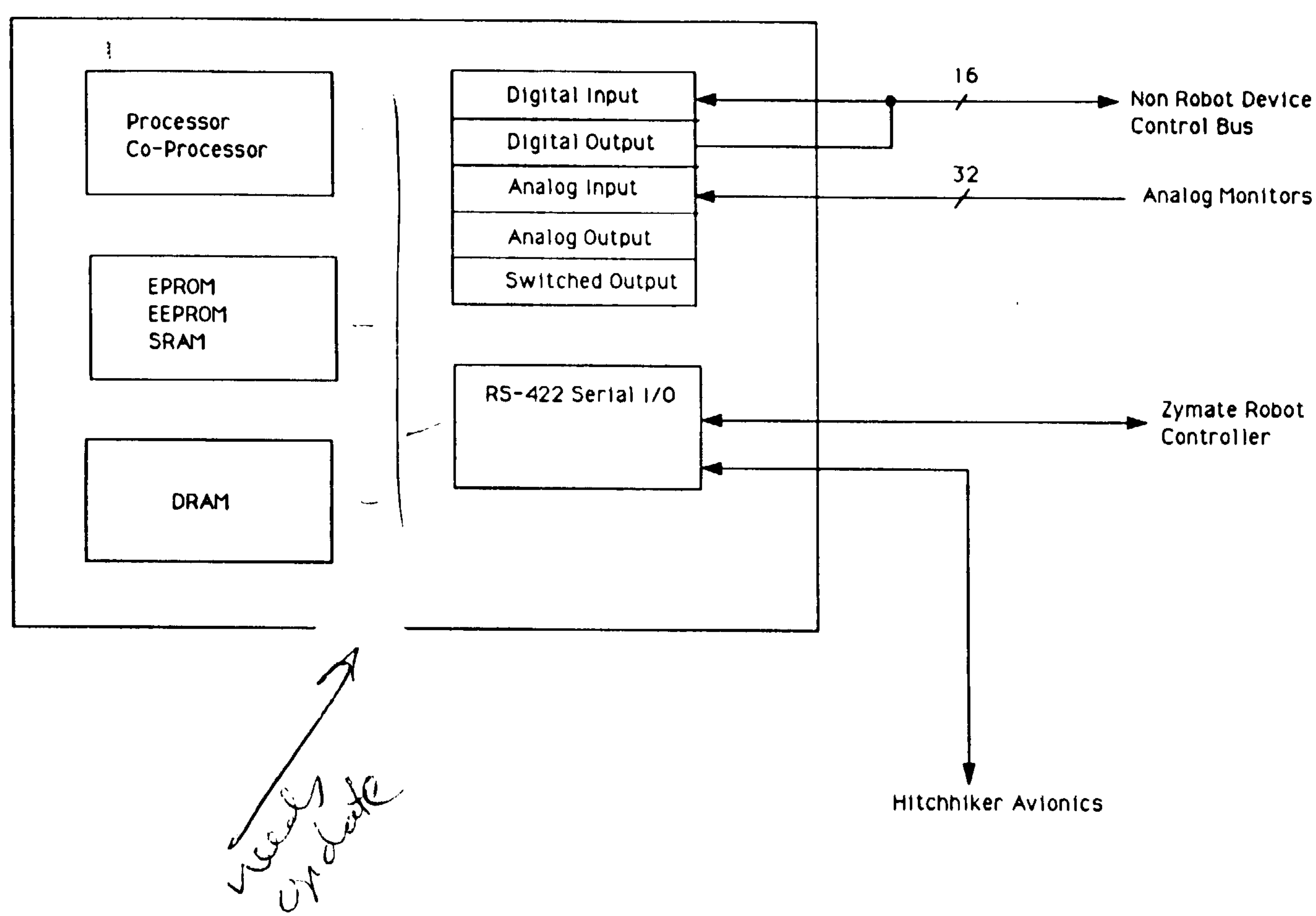
not avail in Zymate to extent req'd

by typical spacecraft cmd system limits?

(Again - no change to update)

Unix real time, exec of command today + tomorrow

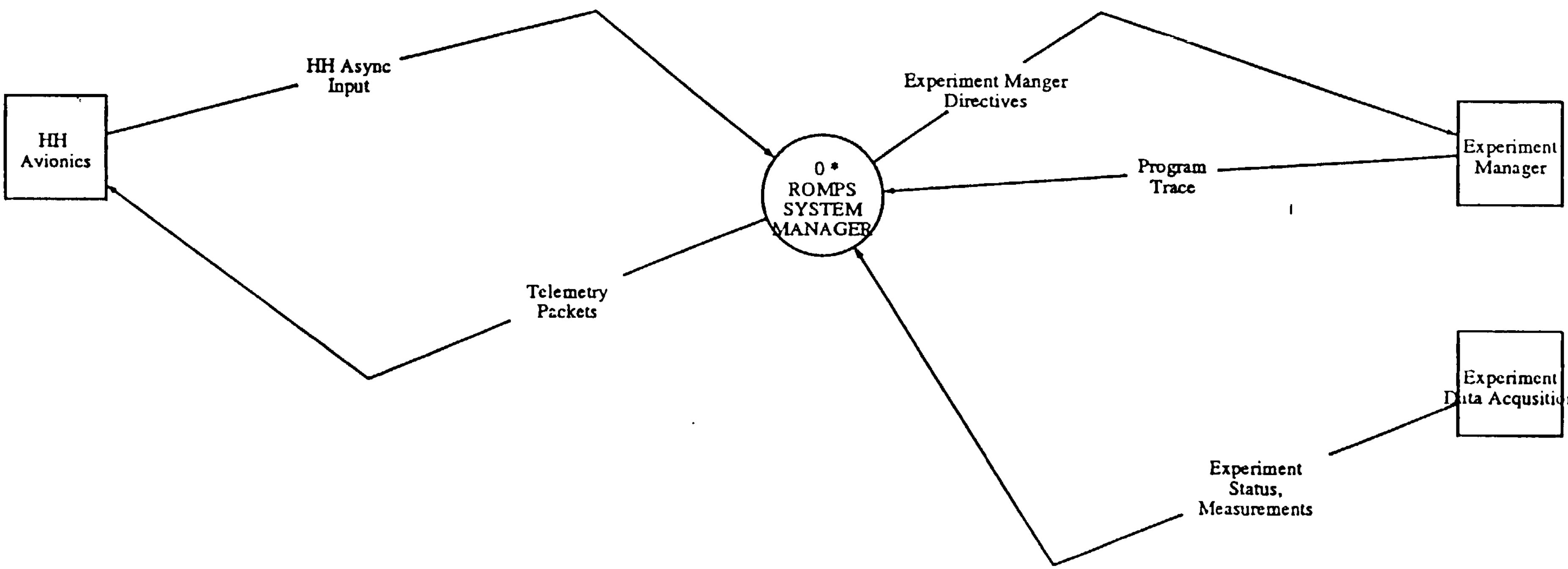
AUTONOMOUS CONTROLLER



ENGINEER M.E.Dobbs	DRAFTSMAN X.X. XXXXXX	XX/XX/XX
SPACE AUTOMATION & ROBOTICS CENTER ENVIRONMENTAL RESEARCH INSTITUTE of MI ANN ARBOR, MI	Autonomous Experiment System Manager Block Diagram RoPMS XXXXXXXXXXXX	XX/XX/XX XX/XX/XX 05/14/91 DATE

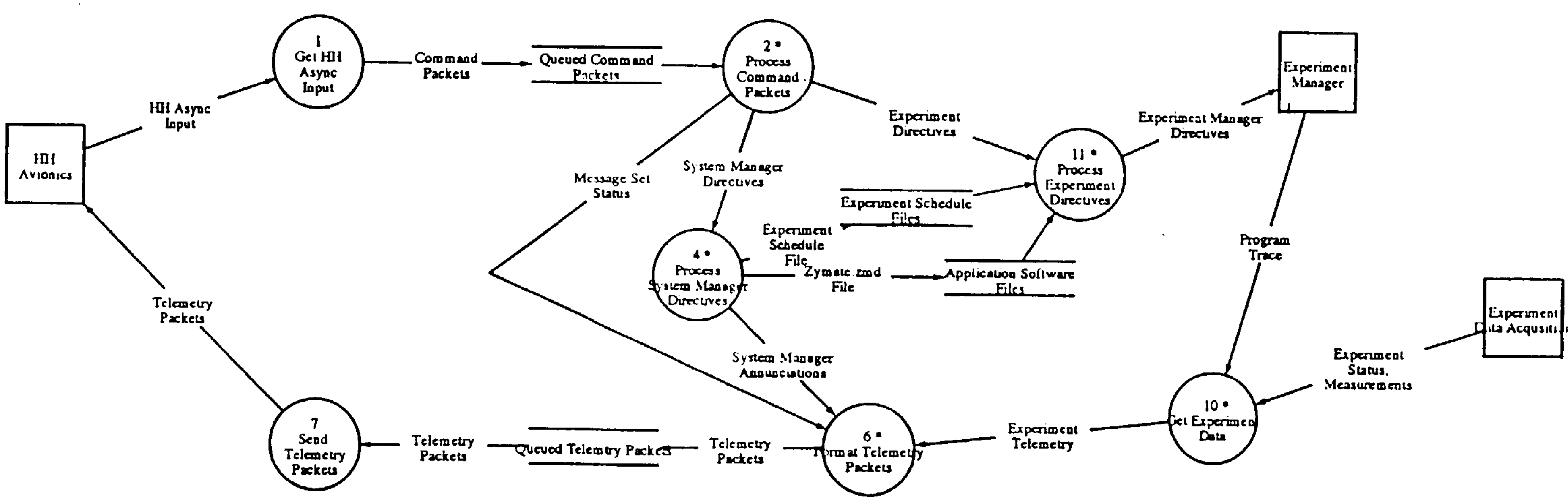
Top Level

romps: level top

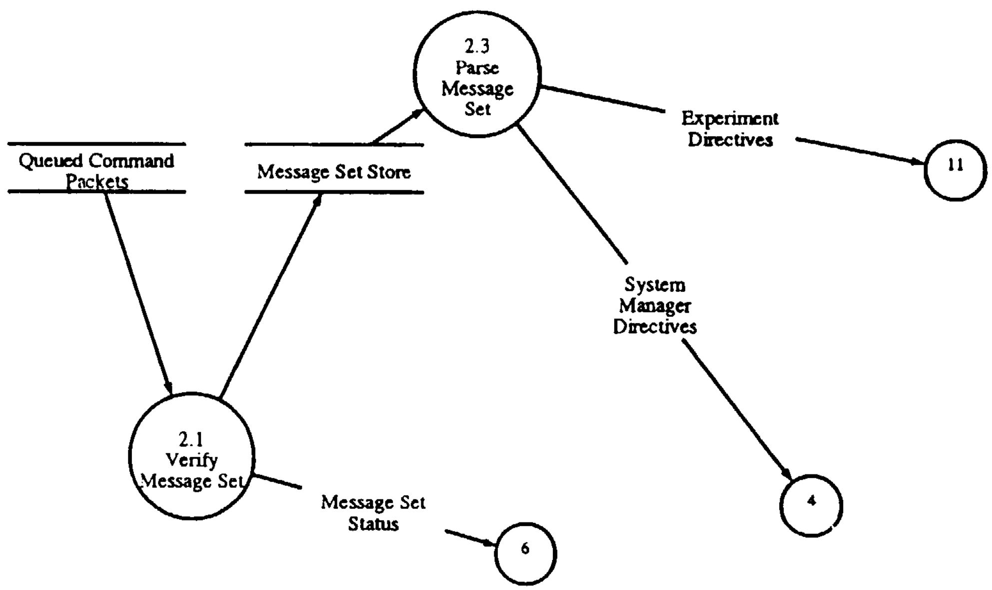


Level 0

romps: level 0

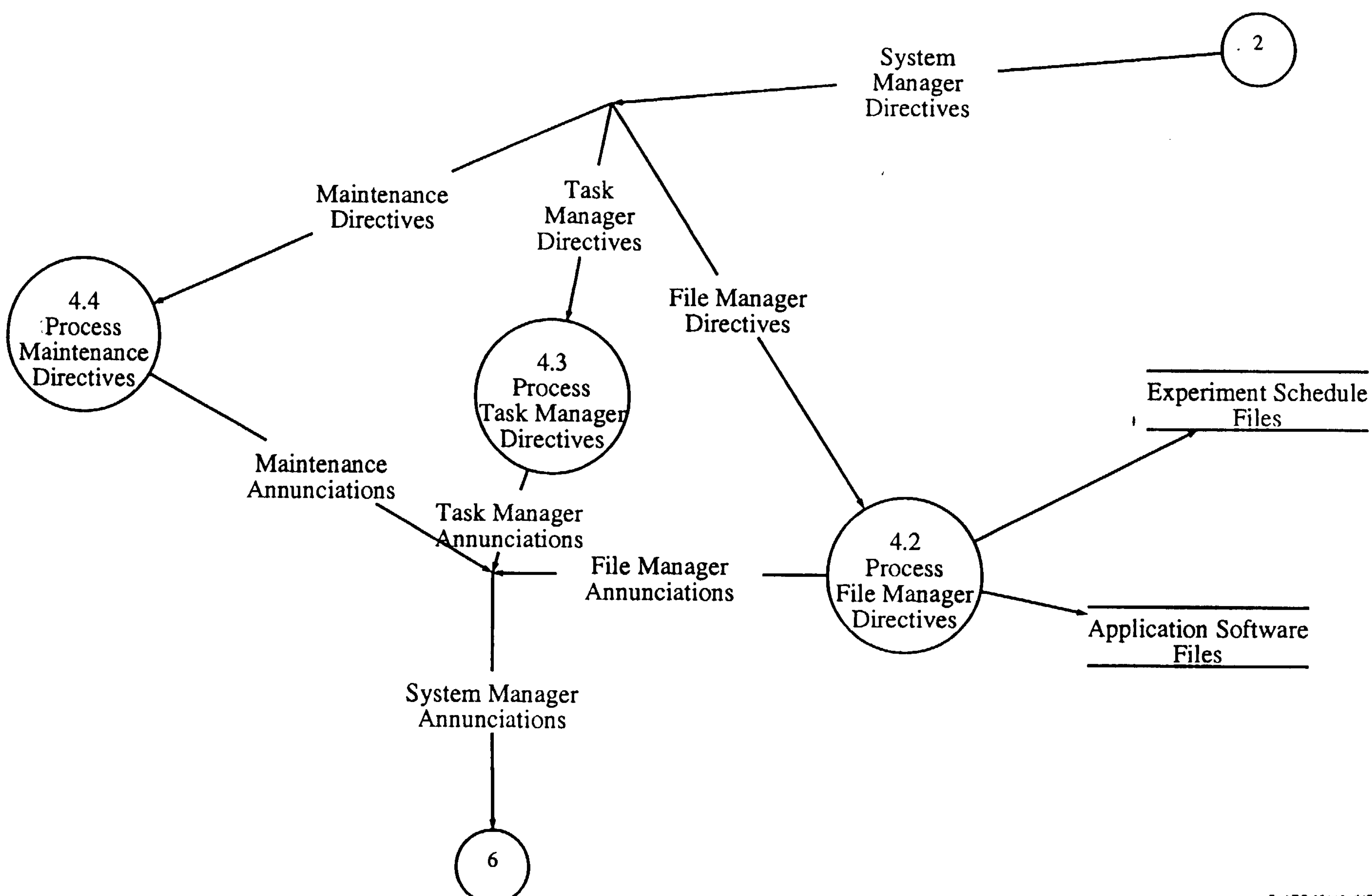


romps: level 2



Format Telemetry Packet

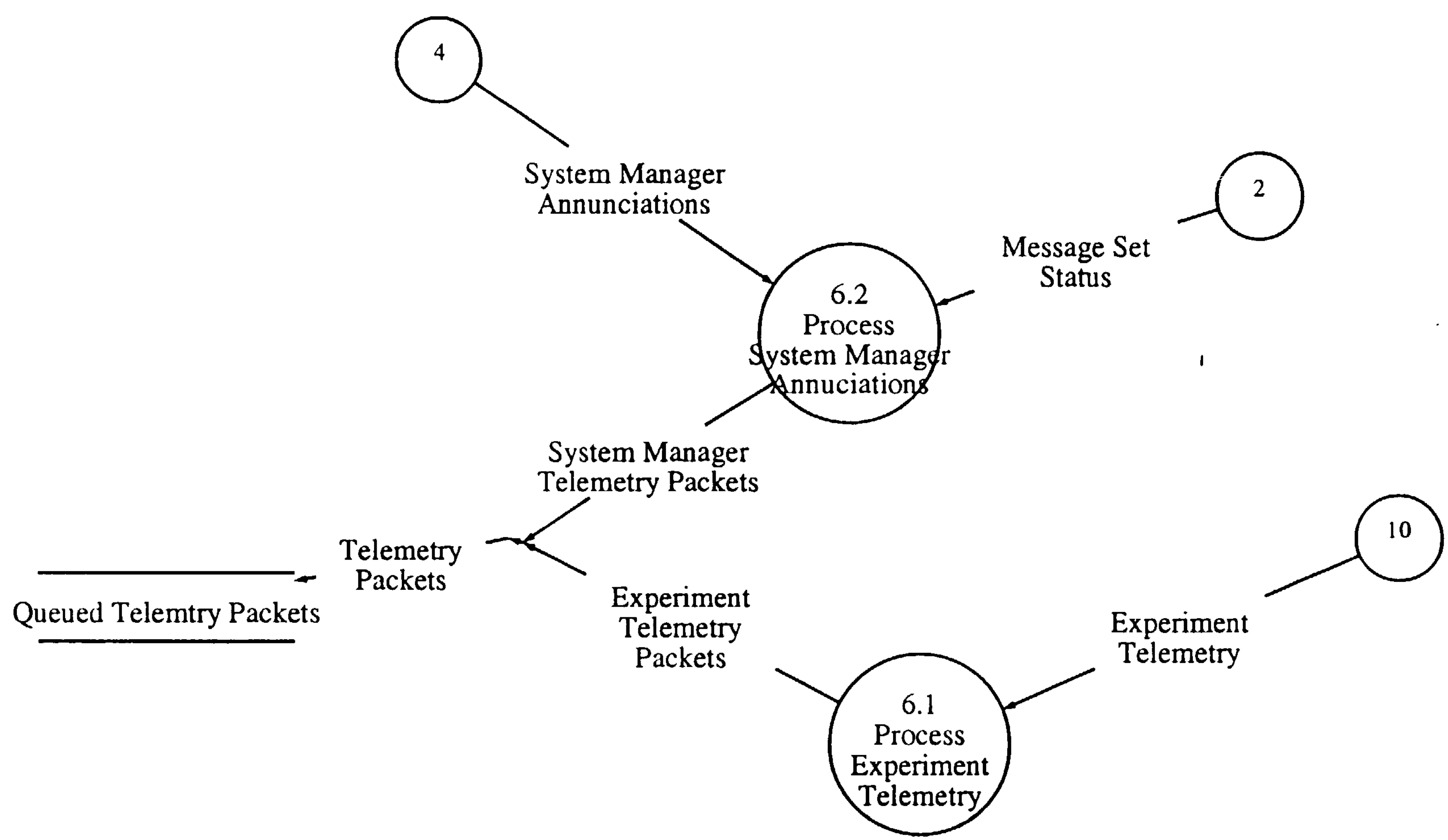
romps: level 4



SpARC 051491/ME1.0

Get Experiment Data

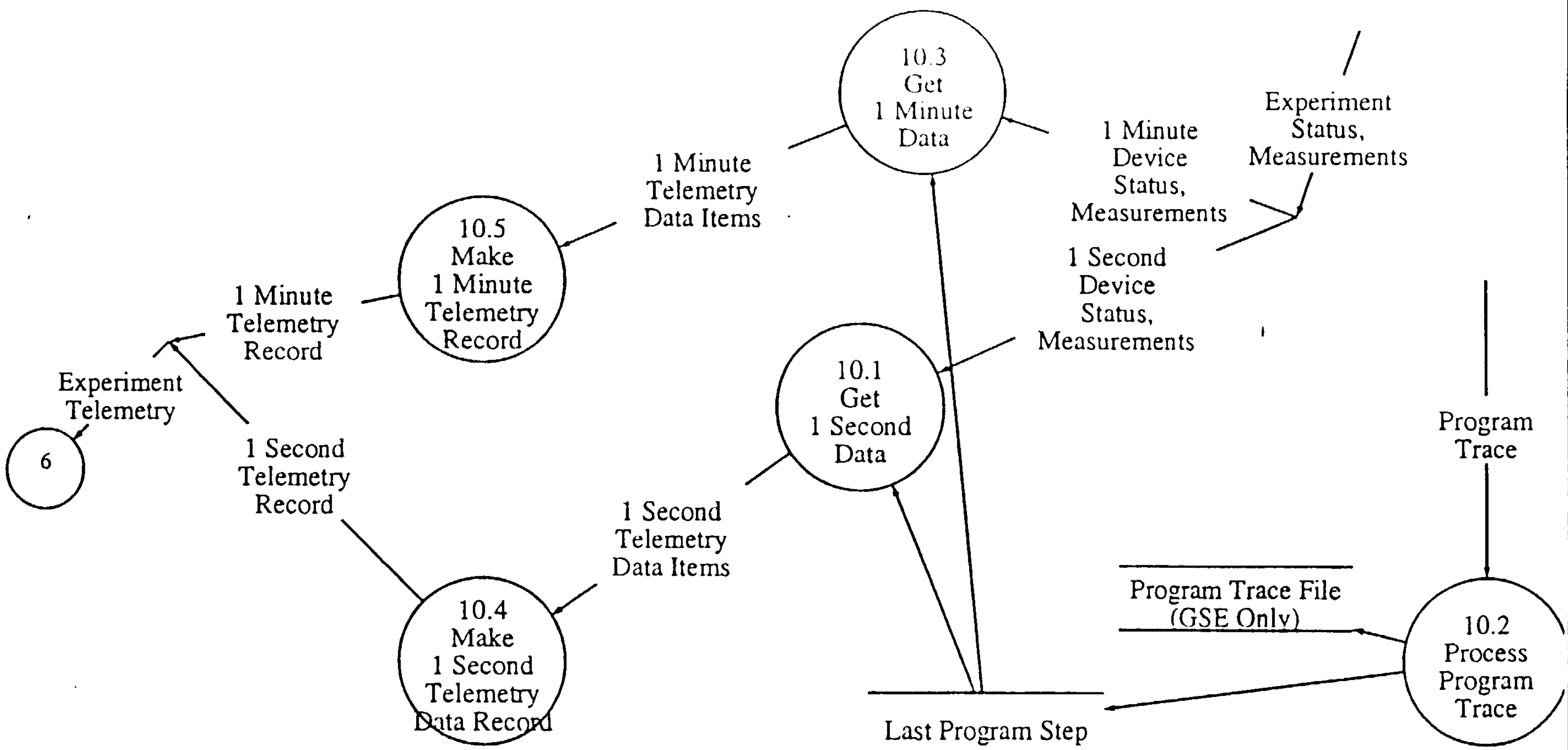
romps: level 6



SpARC 051491/ME1.0

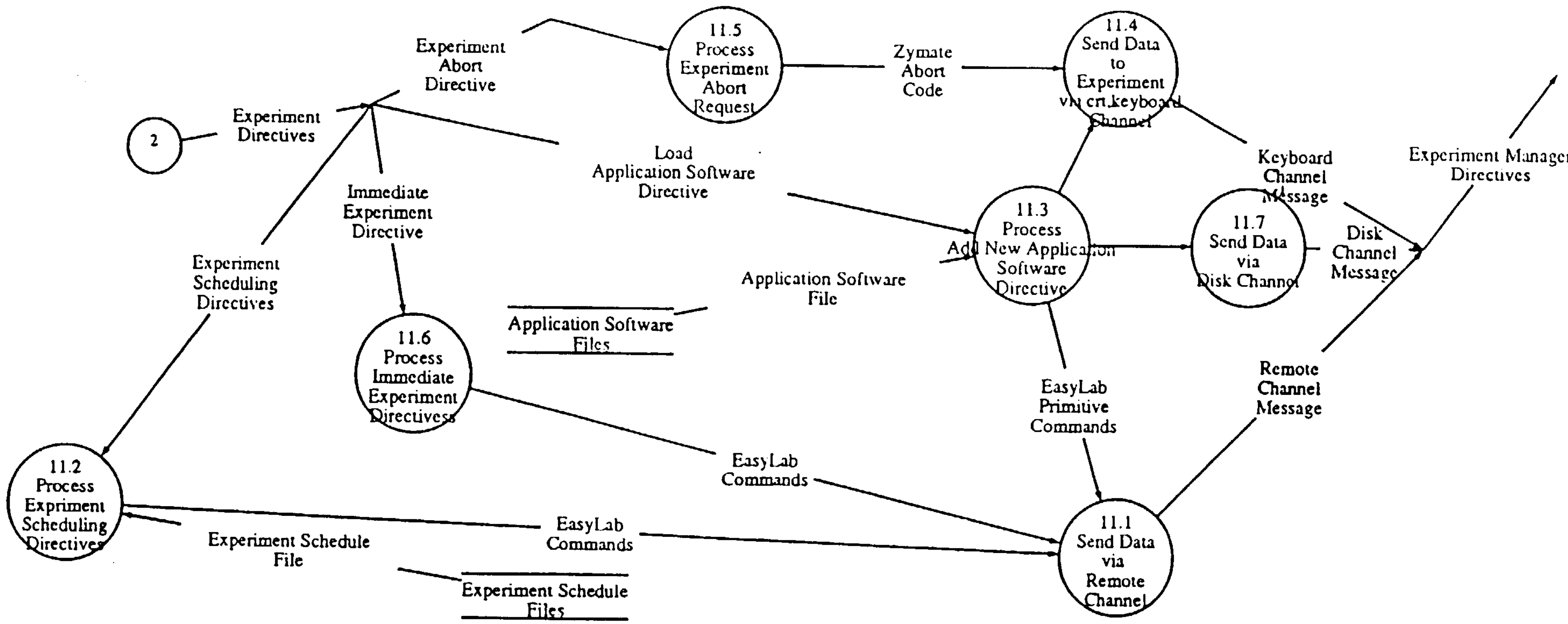
Process Experiment Data

romps: level 10



Process System Directives

romps: level 11



EasyLab™ Command Structure

SpARC Space Automation & Robotics Center

- **EasyLab**
  - **Primitive Commands**
    - Disk Drive Primitives
      - APPEND (Reads from serial connection to sys. manager)
      - DIR*
      - FORMAT*
      - LOAD (from ROM)
      - PYAPPEND*
      - SAVE*
    - System Primitives
      - DIC
      - WARMSTART
  - **Language Commands & Programming Facilities**
    - Math Expressions
      - Comparitors, Functions, Operators
    - Command Variables
      - Input, Output, Bi-directional
    - Dictionary Commands
      - Real Data, Real Data Arrays, String Data
    - String Operators
      - LEN( )
      - STR$( )
      - SUBSTR$(I,J,X$)
      - VAL( )
    - Program Control
      - Branching — GOTO, IF / THEN
      - Looping — DO / ENDDO
      - Synchronization — MODULE WAIT / NO MODULE WAIT
      - Pausing — TIMER( ) / WAIT FOR TIMER
      - Logging — DISPLAY ON/OFF
      - Time — CLOCK
    - Input/Output*
      - Numeric, string, & HHOT input — INPUT, INPUT$, INPUT#H
      - Screen & HHOT display — ?, PRINT, PRINTC, PRINT#H
      - Display design — ERASE, PROMPT, PFORMAT
      - Data files — OPEN, CLOSE, PRINT#1, INPUT#1
    - Other*
      - BEEP
      - DELETE
      - NOW$
      - REDUCE

*Not supported in SC-4 port.

SpARC 051491/MC1.0

IMPLEMENTATION OPTIONS FOR THE ROBOT MOVEMENT
EasyLab™ Language Interface.

PUT.INTO.ANNEALER

```
MOVE.IN.SAFE
MOVE.ANNEALER
MOVE.BELOW.ANNEALER
MOVE.UP.INTO.ANNEALER
```

This implementation uses a set of "learned" absolute and relative positions. This method is supported and available in the current EasyLab™.
NOTE : As these positions are stored in the system data dictionary their values can be modified.

```
S:ALL.SPEED = 1.0
S:THETA= SAFE.RADIAL
S:RADIAL = ANNEALER.RADIAL
S:Z= ANNEALER.HEIGHT
S:THETA = S:THETA +
            ANNEALER.THETA
S:HEIGHT = UP.TO.ALLEALER
```

This implementation uses EasyLab™ Command Variables. Assignment to these variables causes the variable state to change and an action to occur. Again, this is still a method used and supported by EasyLab™.

```
S:ALL.SPEED = 1.0
S:THETA= SAFE
MOVE.THETA
S:RADIAL = ANNEALER.RADIAL
S:Z= ANNEALER.HEIGHT
MOVE.ALL
S:THETA = S:THETA +
            ANNEALER.THETA
MOVE.THETA
S:HEIGHT = UP.TO.ANNEALER
MOVE.HEIGHT
```

This implementation uses command variables in a different manner than the current EasyLab™ robot movement language.
Command variables do not cause the robot movement to occur.
Instead, movement is initiated by a simple command which uses the previously set variable states as its inputs. This implementation would be easy to accomplish with the current EasyLab™ interpreter.

```
MOVE "THETA" , ALL.SPEED,
        SAFE.THETA
MOVE "RADIAL", ALL.SPEED,
        ANNEALER.RADIAL
MOVE "Z", ALL.SPEED,
        ANNEALER.HEIGHT
MOVE.REL "THETA", ALL.SPEED
        BELOW.ANNEALER
MOVE.REL "THETA" ,ALL.SPEED,
        UP.ANNEALER
```

This implementation uses a currently unavailable zymate interpreter ability, parameter passing. There are no plans for this to be implemented in the port to the SC-4 system.

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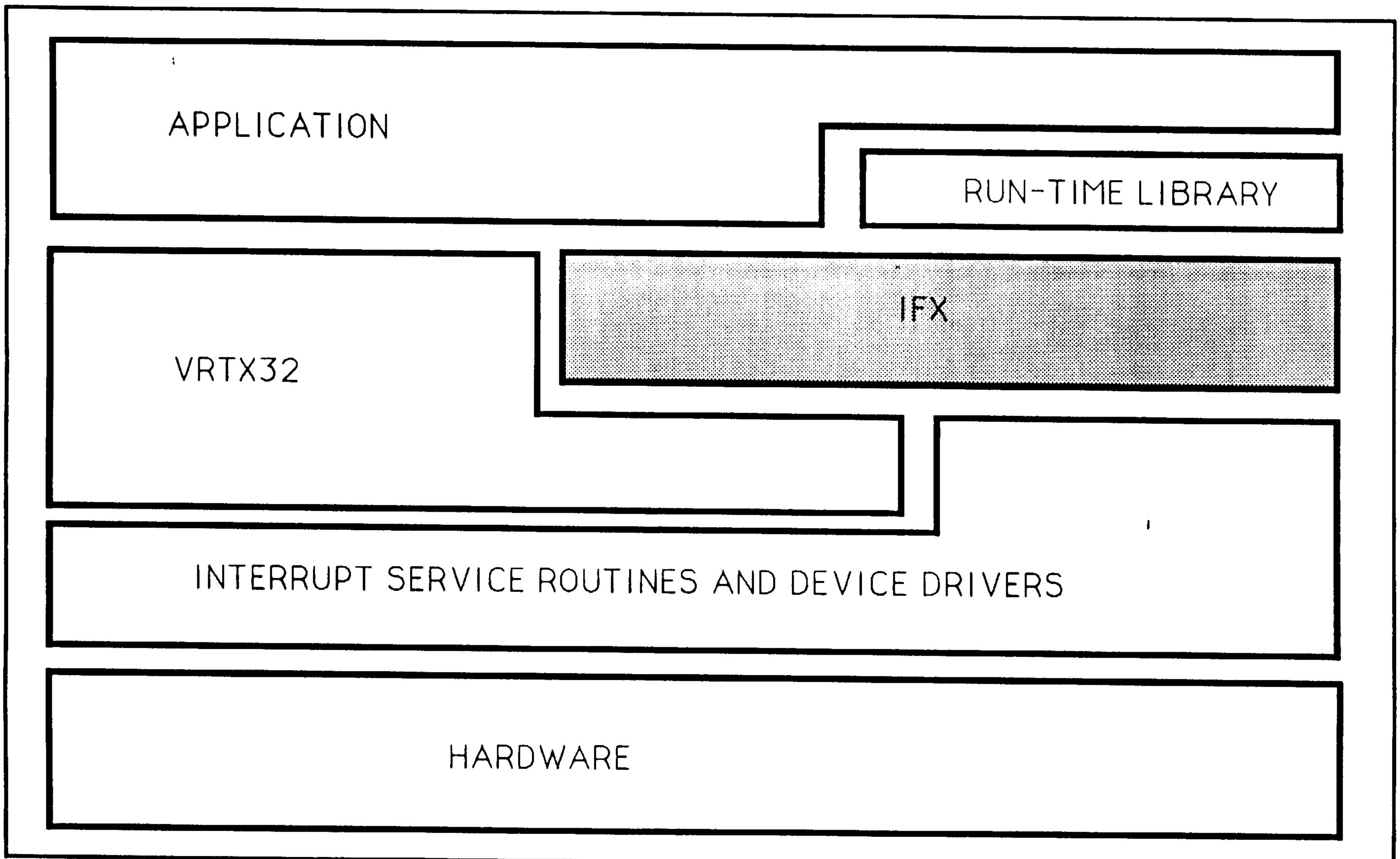
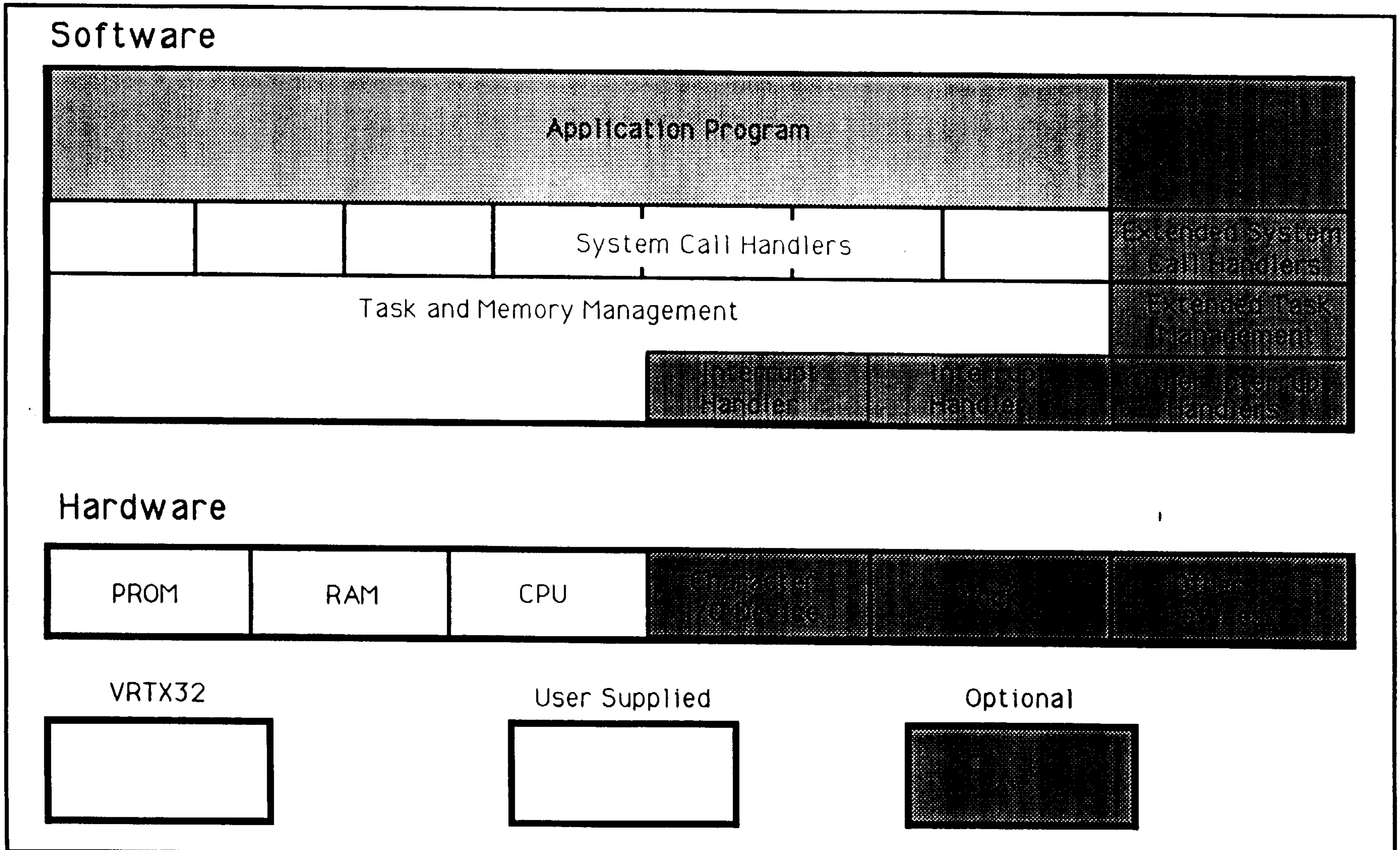


ENGINEER M.E Dobbs	DRAFTSMAN X X XXXXXXX	XX/XX/XX
SPACE AUTOMATION & ROBOTICS CENTER	VRTX Multi-Tasking Real-Time System	XX/XX/XX
ENVIRONMENTAL RESEARCH INSTITUTE of MI	AESM Data Flow Diagrams	XX/XX/XX
ANN ARBOR, MI	RoMPS	05/14/91
	XXXXXXXXXXXX	DATE



ENGINEER M.E. Dobbs	DRAFTSMAN X. X. XXXXXXX	XX/XX/XX
SPACE AUTOMATION & ROBOTICS CENTER	VRTX Multi-Tasking Real-Time Kernel	XX/XX/XX
ENVIRONMENTAL RESEARCH INSTITUTE of MI	AESM Data Flow Diagrams	XX/XX/XX
ANN ARBOR, MI	RoMPS	05/14/91
	XXXXXXXXXXXX	DATE

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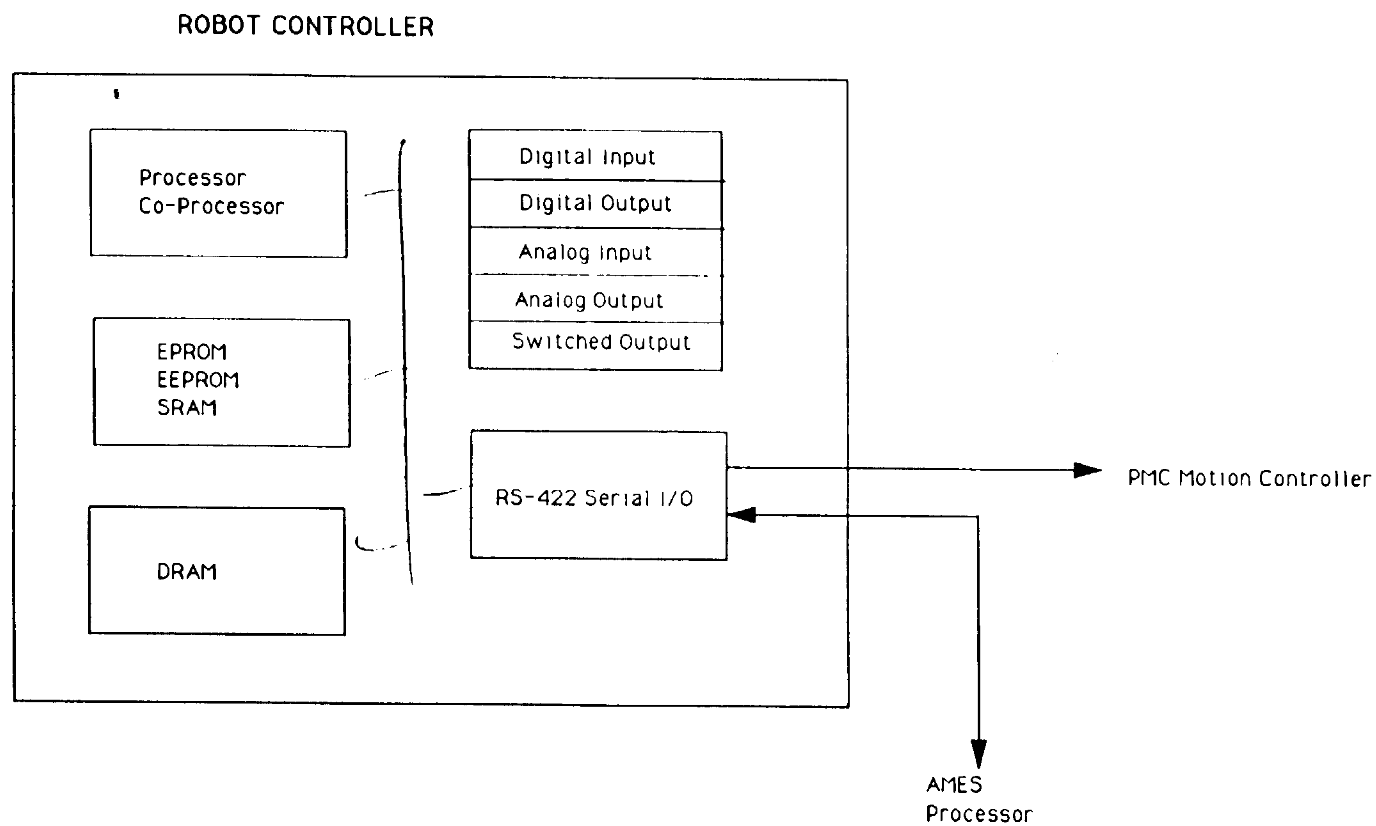

ENGINEER X. X. XXXXXXX	DRAFTSMAN X. X. XXXXXXX	XX/XX/XX
		XX/XX/XX
SPACE AUTOMATION & ROBOTICS CENTER	Zymate Robot Controller Block Diagram	XX/XX/XX
ENVIRONMENTAL RESEARCH INSTITUTE of MI	RoMPS	05/14/91
ANN ARBOR, MI	XXXXXXXXXXXX	DATE

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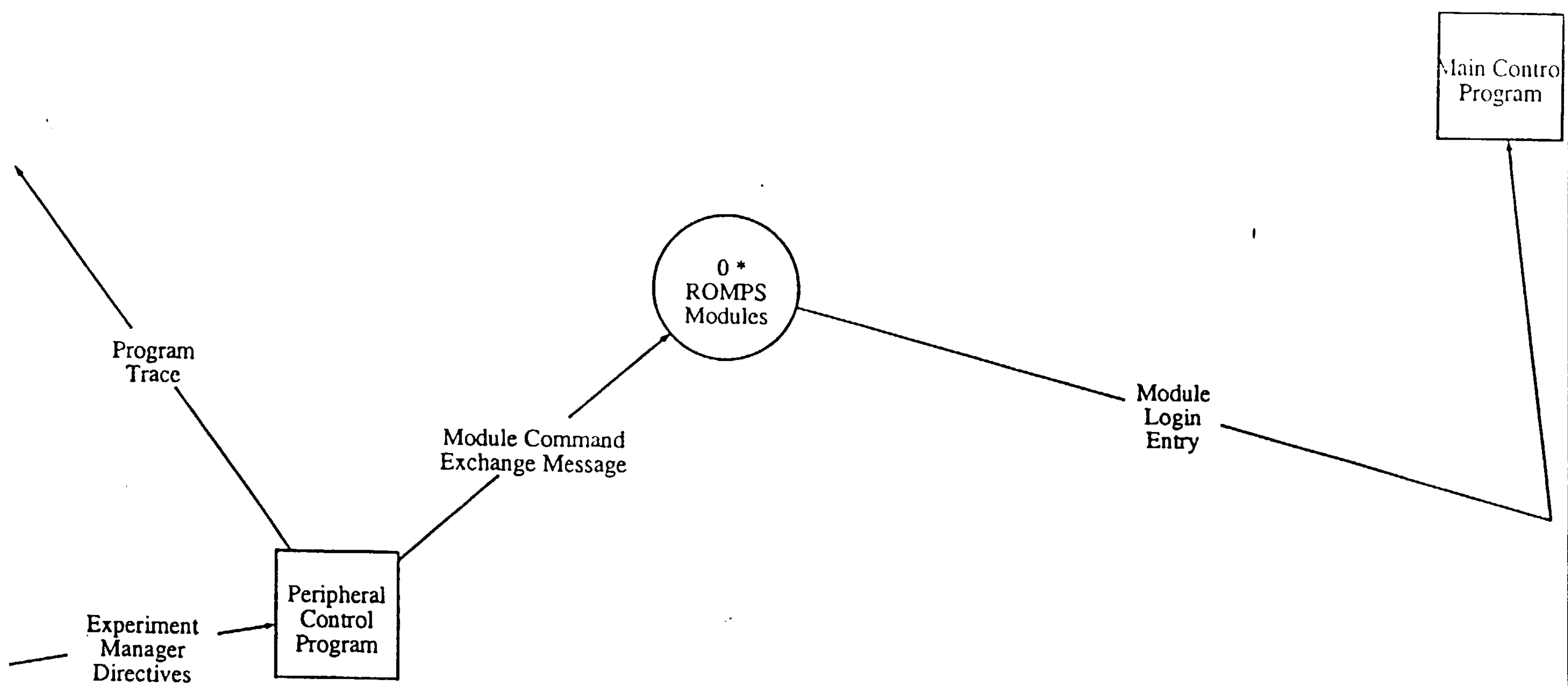
zymate: level top



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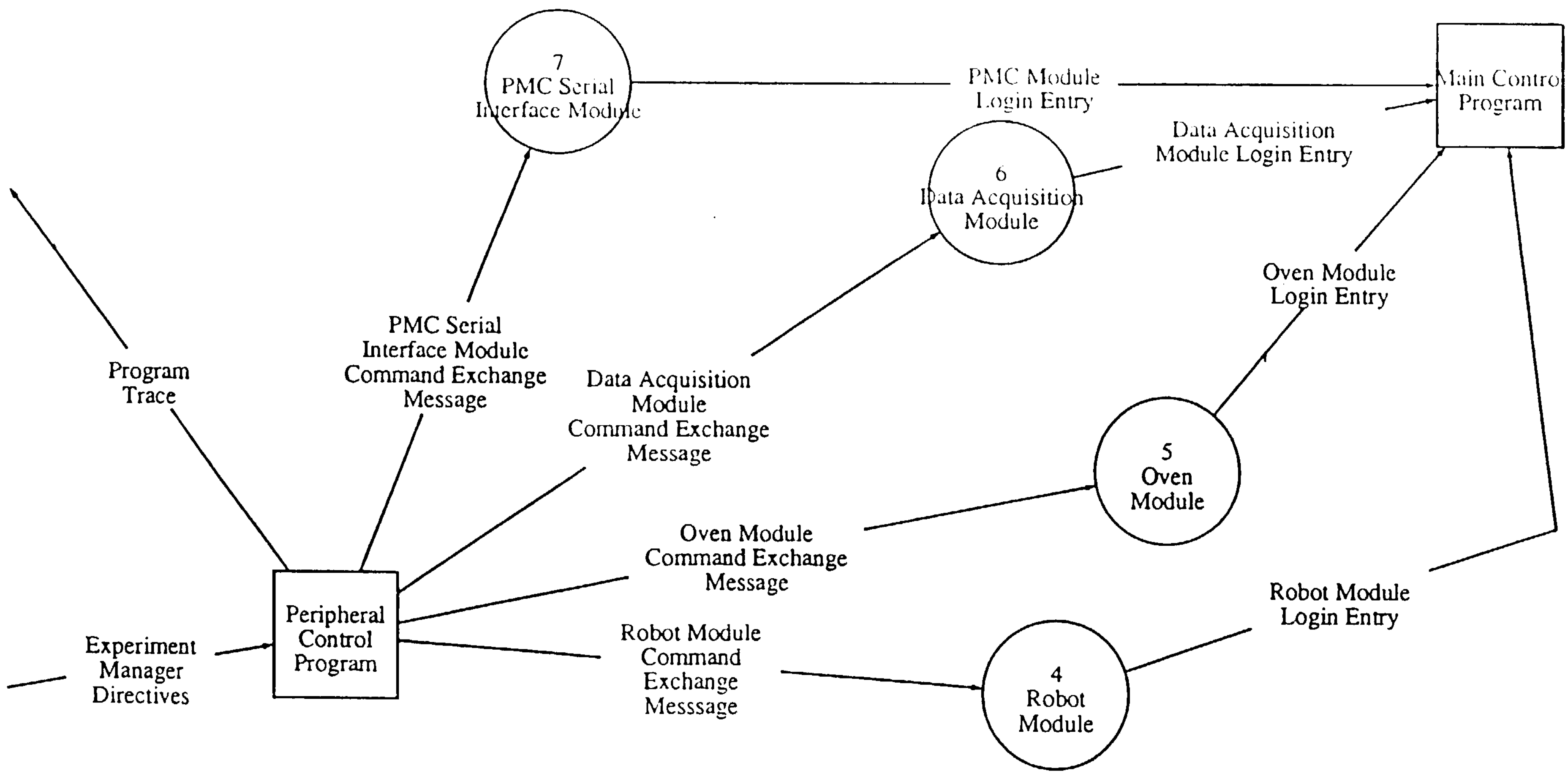
Level 0

zymate: level 0



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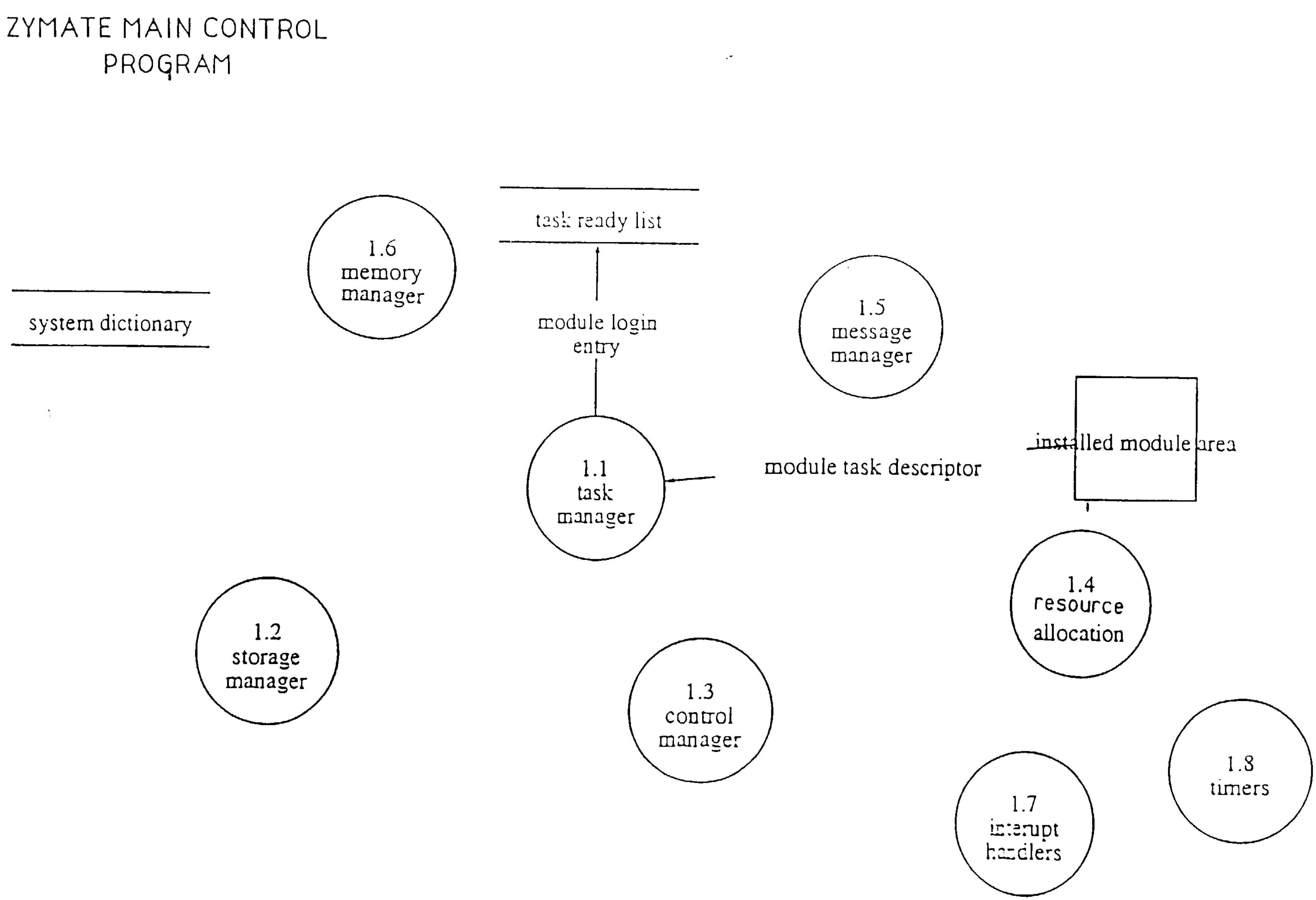
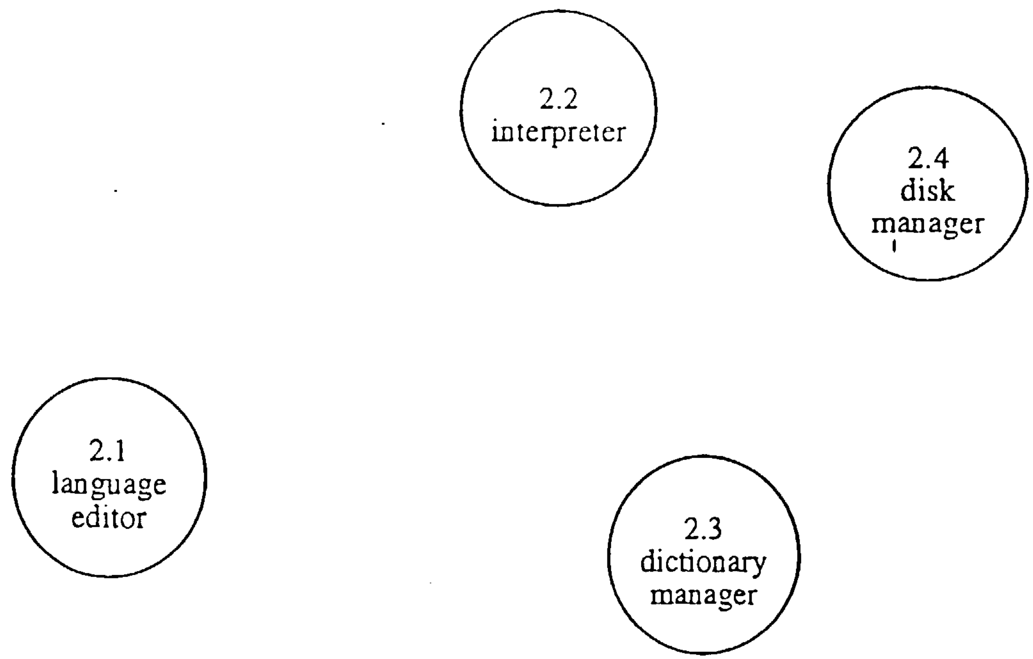
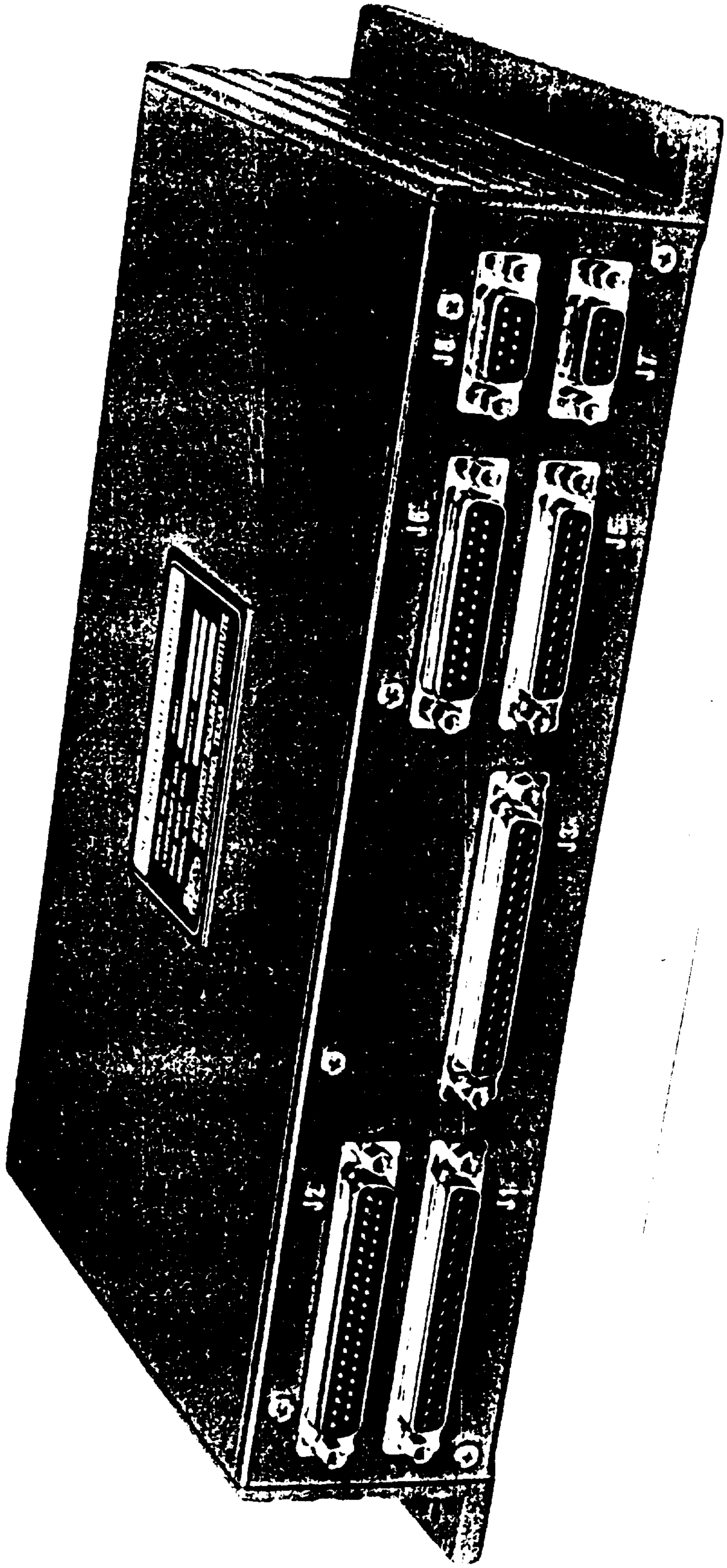
Main Control



SpARC
Space Automation & Robotics Center

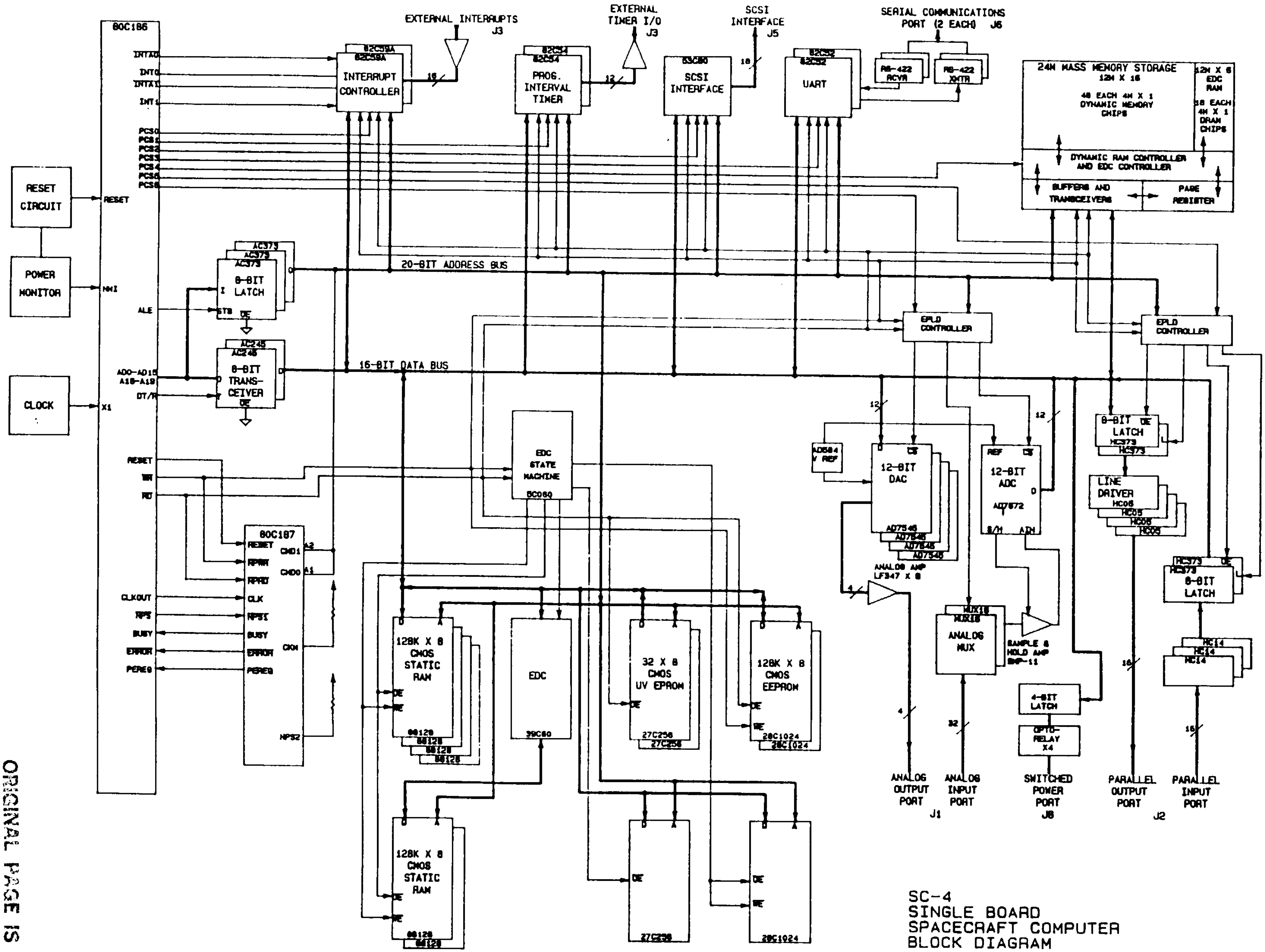
ZYMATE PERIPHERAL
CONTROL PROGRAM




J8
J7
J6
J5
J3
J2
J1

Preliminary Specification
SC-4 Single Board Spacecraft Computer

Central Processor	80C186/80C187 16 Bit
Clock Frequency	10 MHz
Operating System	MS-DOS and VRTX Compatible
Onboard Memory	
RAM	512K Bytes w/EDC
EEPROM	256K Bytes
UVPROM	64K Bytes
Hardware Vectored Interrupts	16 User Configurable
Timer/Event Counters	6, Software Configurable, 120 ns Granularity
Input/Output Capability	
Parallel I/O	16 Input, 16 Output
Analog Input	32 Differen solution,
Analog Output	4 Channels
RS-422 Serial I/O	2 Channels
SCSI Interface	1 Port
Mass Storage	24M Bytes, F olatile
Expansion	Internal Daug ector
Size	7 X 12 X 2.25 in
Weight	5 Lb (Approximate)
Power	28v @ 5w (Approximate)



SC-4
SINGLE BOARD
SPACECRAFT COMPUTER
BLOCK DIAGRAM

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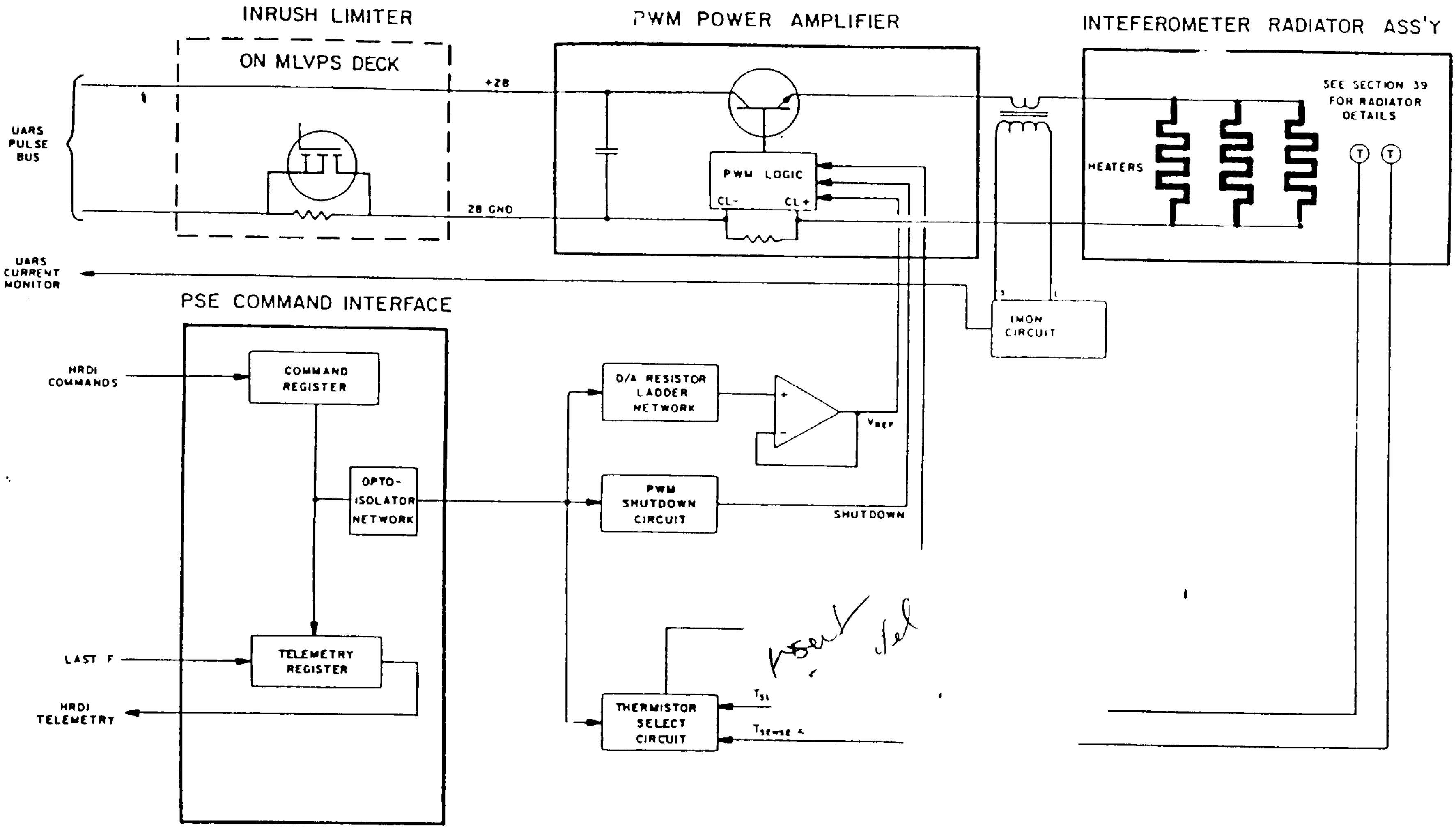
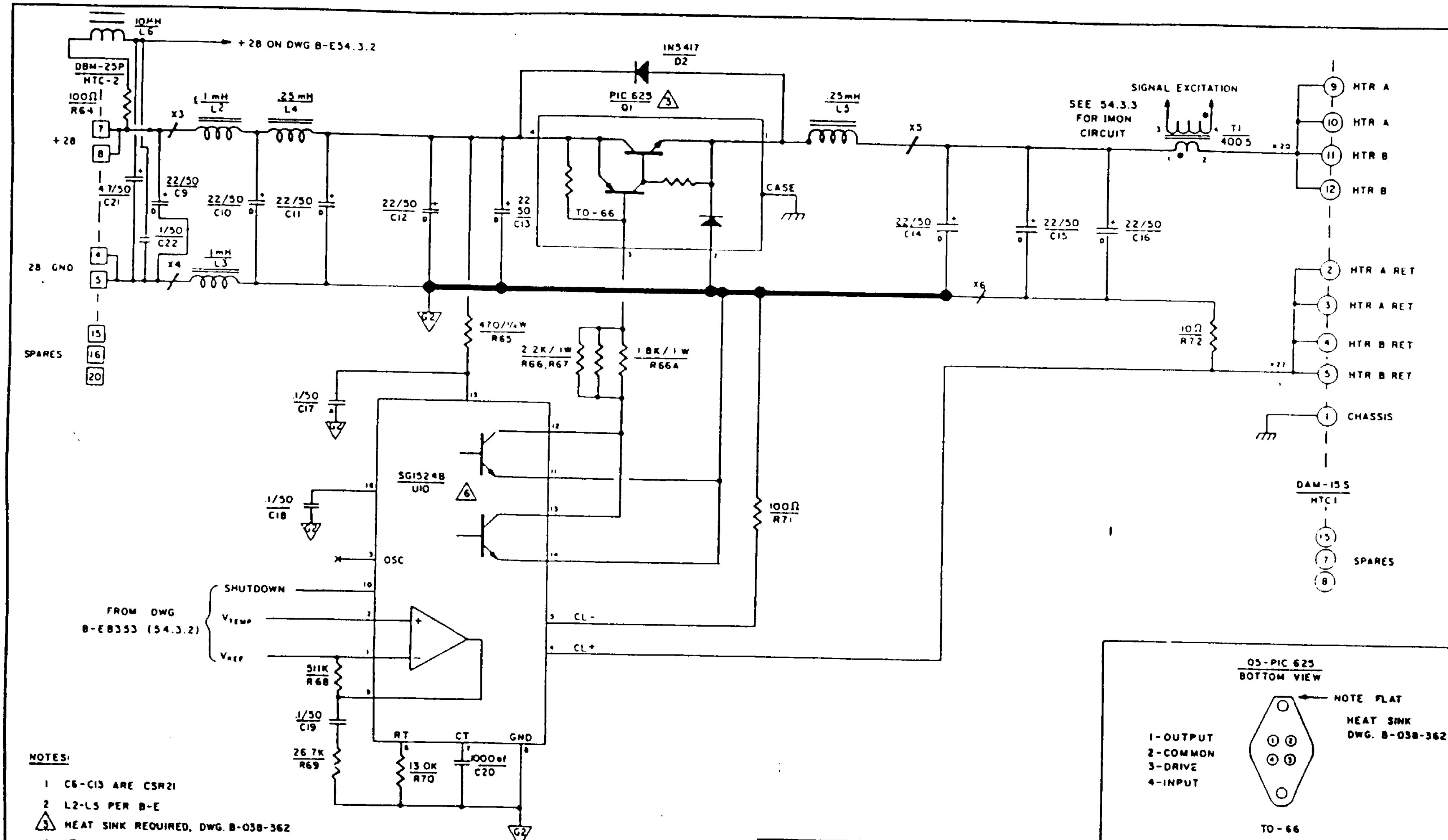
Oven Control

Housekeeping Data



ENGINEER J. STEVENS	DRAFTER EGJ REK 4/9/87	
SPACE PHYSICS RESEARCH LABORATORY	IF THERMAL CONTROLLER	
COLLEGE OF ENGINEERING	BLOCK DIAGRAM	2/1/89
UNIVERSITY OF MICHIGAN	HRDI UARS PSE	7/15/88
ANN ARBOR, MICHIGAN	B-E8033 CONTROLLED	DATE

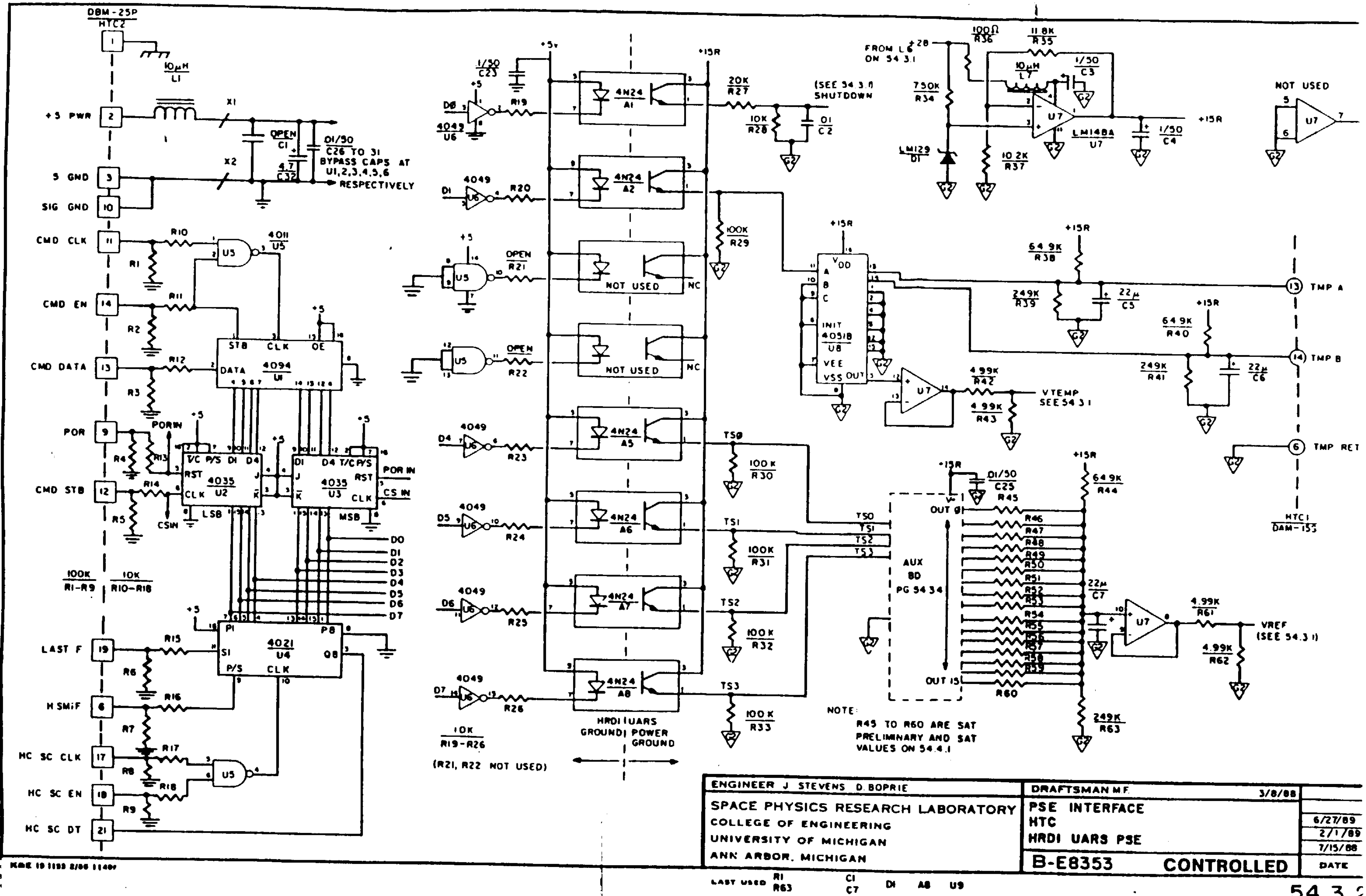


NOTES:

1. C6-C13 ARE CSR21
2. L2-L5 PER B-E
3. HEAT SINK REQUIRED, DWG. B-038-362
4. X3, X4, X5, X6 ARE FERRITE BEADS
5. SAT
6. HEAT SINK REQUIRED, DWG. A-038-

ENGINEER J. STEVENS D. BOPRIE	DRAFTER EGJ 4/22/87
SPACE PHYSICS RESEARCH LABORATORY COLLEGE OF ENGINEERING UNIVERSITY OF MICHIGAN ANN ARBOR, MICHIGAN	PWM DRIVER HTC HRDI UARS PSE
	B-E8035 CONTROLLED

LAST USED R 72 C 22 D2 Q1 L 6



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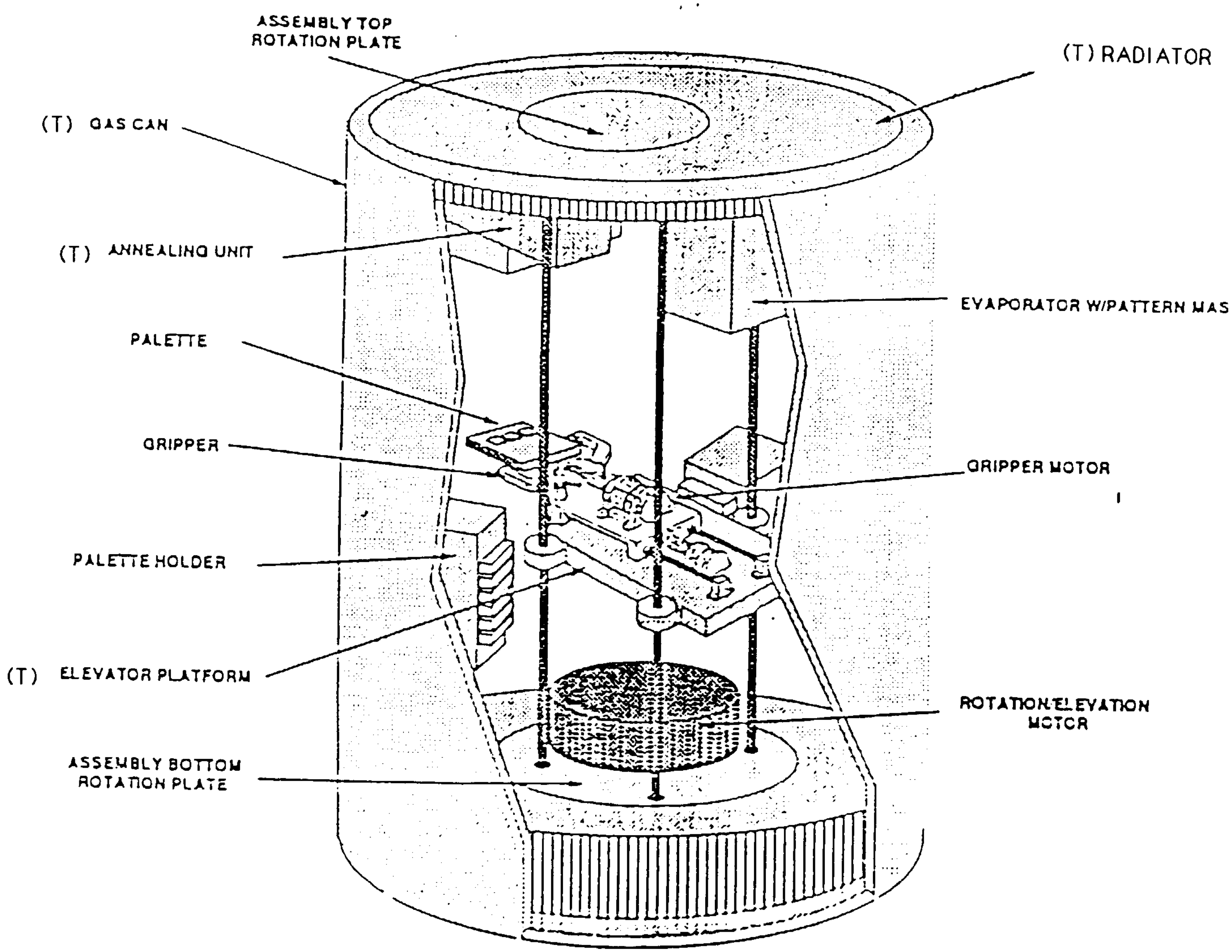
ROBOT THERMISTER LOCATIONS

SpARC Space Automation & Robotics Center

GAS CAN CONCEPT LAYOUT



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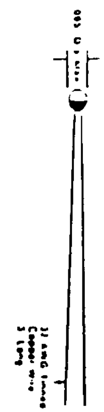
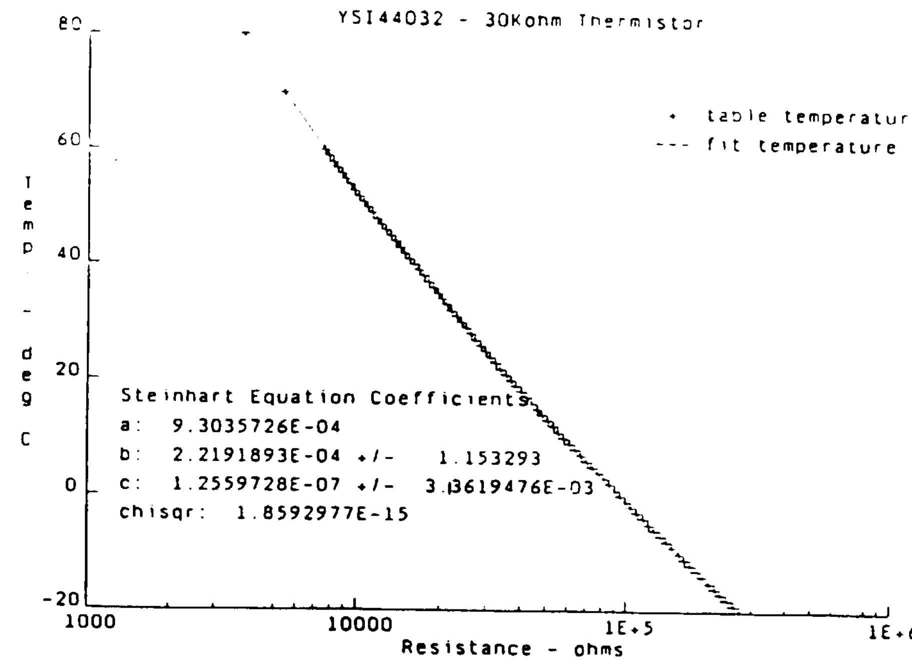
SpARC 051491/ME1.0

RESISTANCE VERSUS TEMPERATURE — 40° to +100°									
TEMP°C	RES	TEMP°C	RES	TEMP°C	RES	TEMP°C	RES	TEMP°C	RES
−40	884 6K	−10	158 0K	+20	37 30K	+50	10 97K	+80	3843
39	830 9K	9	150 0K	21	35 70K	51	10 57K	81	3720
38	780 8K	8	142 4K	22	34 17K	52	10 18K	82	3602
37	733 9K	7	135 2K	23	32 71K	53	9807	83	3489
36	690 7K	6	128 5K	24	31 32K	54	9450	84	3379
35	649 3K	5	122 1K	25	30 00K	55	9109	85	3273
34	611 0K	4	116 0K	26	28 74K	56	8781	86	3172
33	575 2K	3	110 3K	27	27 54K	57	8467	87	3073
32	541 7K	2	104 9K	28	26 40K	58	8166	88	2979
31	510 4K	−1	99 80K	29	25 31K	59	7876	89	2887
−30	481 0K	0	94 98K	+30	24 27K	+60	7599	+90	2799
29	453 5K	+1	90 41K	31	23 28K	61	7332	91	2714
28	427 7K	2	86 09K	32	22 33K	62	7076	92	2632
27	403 5K	3	81 99K	33	21 43K	63	6830	93	2552
26	380 9K	4	78 11K	34	20 57K	64	6594	94	2478
25	359 6K	5	74 44K	35	19 74K	65	6367	95	2402
24	339 6K	6	70 96K	36	18 96K	66	6149	96	2331
23	320 9K	7	67 66K	37	18 21K	67	5940	97	2262
22	303 3K	8	64 53K	38	17 49K	68	5738	98	2195
21	286 7K	9	61 56K	39	16 80K	69	5545	99	2131
−20	271 2K	+10	58 75K	+40	16 15K	+70	5359	+100	2069
19	256 5K	11	56 07K	41	15 52K	71	5180		
18	242 8K	12	53 54K	42	14 92K	72	5007		
17	229 8K	13	51 13K	43	14 35K	73	4842		
16	217 6K	14	48 84K	44	13 80K	74	4682		
15	206 2K	15	46 67K	45	13 28K	75	4529		
14	195 4K	16	44 60K	46	12 77K	76	4381		
13	185 2K	17	42 64K	47	12 29K	77	4239		
12	175 6K	18	40 77K	48	11 83K	78	4107		
11	166 6K	19	38 99K	49	11 39K	79	3970		





ENGINEER M.DOBBS	DRAFTSMAN M F 6/10/87	
SPACE PHYSICS RESEARCH LABORATORY COLLEGE OF ENGINEERING UNIVERSITY OF MICHIGAN ANN ARBOR, MICHIGAN	TEMPERATURE ALGORITHMS 2 OF 2 INTERFEROMETER HOUSEKEEPING HRDI UARS	6/10/
	B-E8154 CONTROLLED	DATE

LAST USED R C D L

23.1

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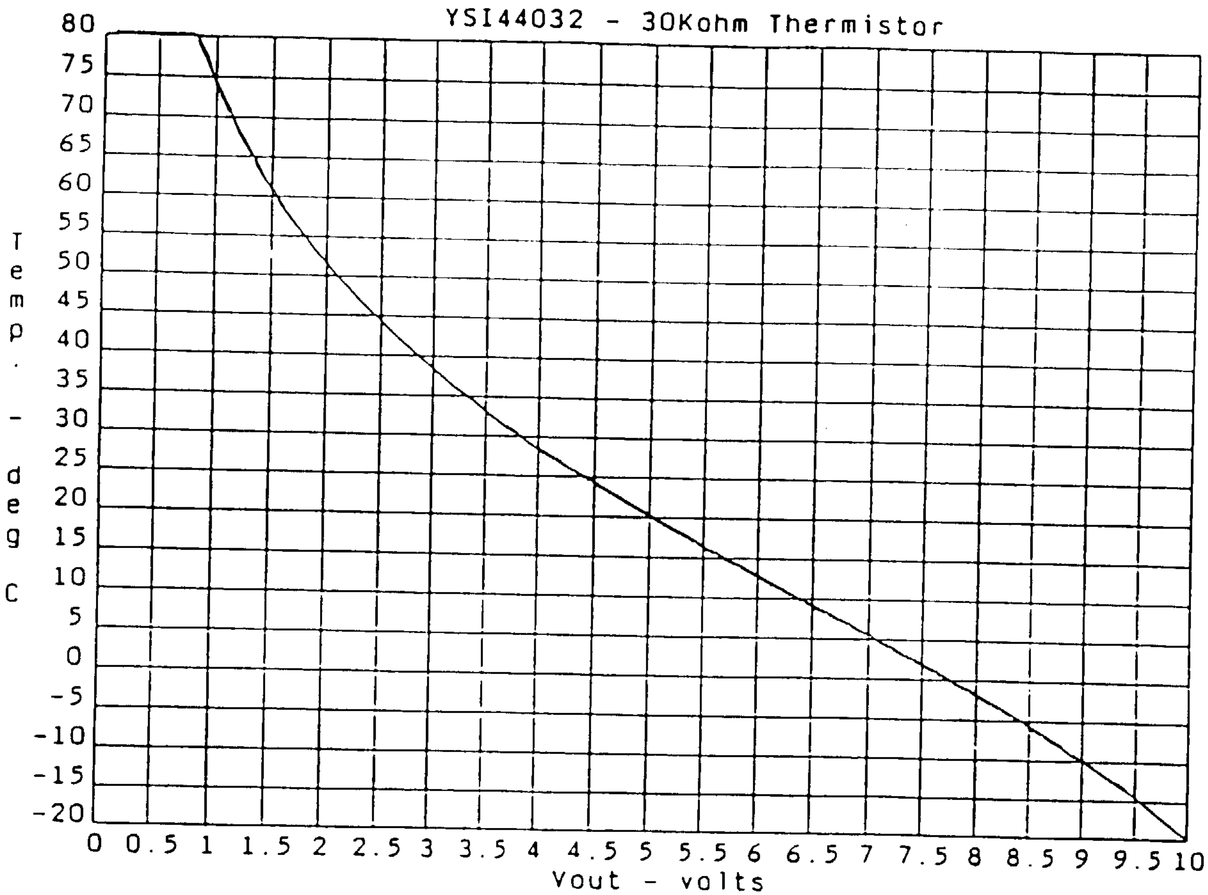

ENGINEER M DOBBS	DRAFTSMAN MF 6/30/87
SPACE PHYSICS RESEARCH LABORATORY COLLEGE OF ENGINEERING UNIVERSITY OF MICHIGAN ANN ARBOR, MICHIGAN	TEMPERATURE CALIBRATION CURVE INTERFEROMETER HOUSEKEEPING HRDI UARS
	B-E8204 CONTROLLED

6/10/87
DATE

LAST USED R C D L

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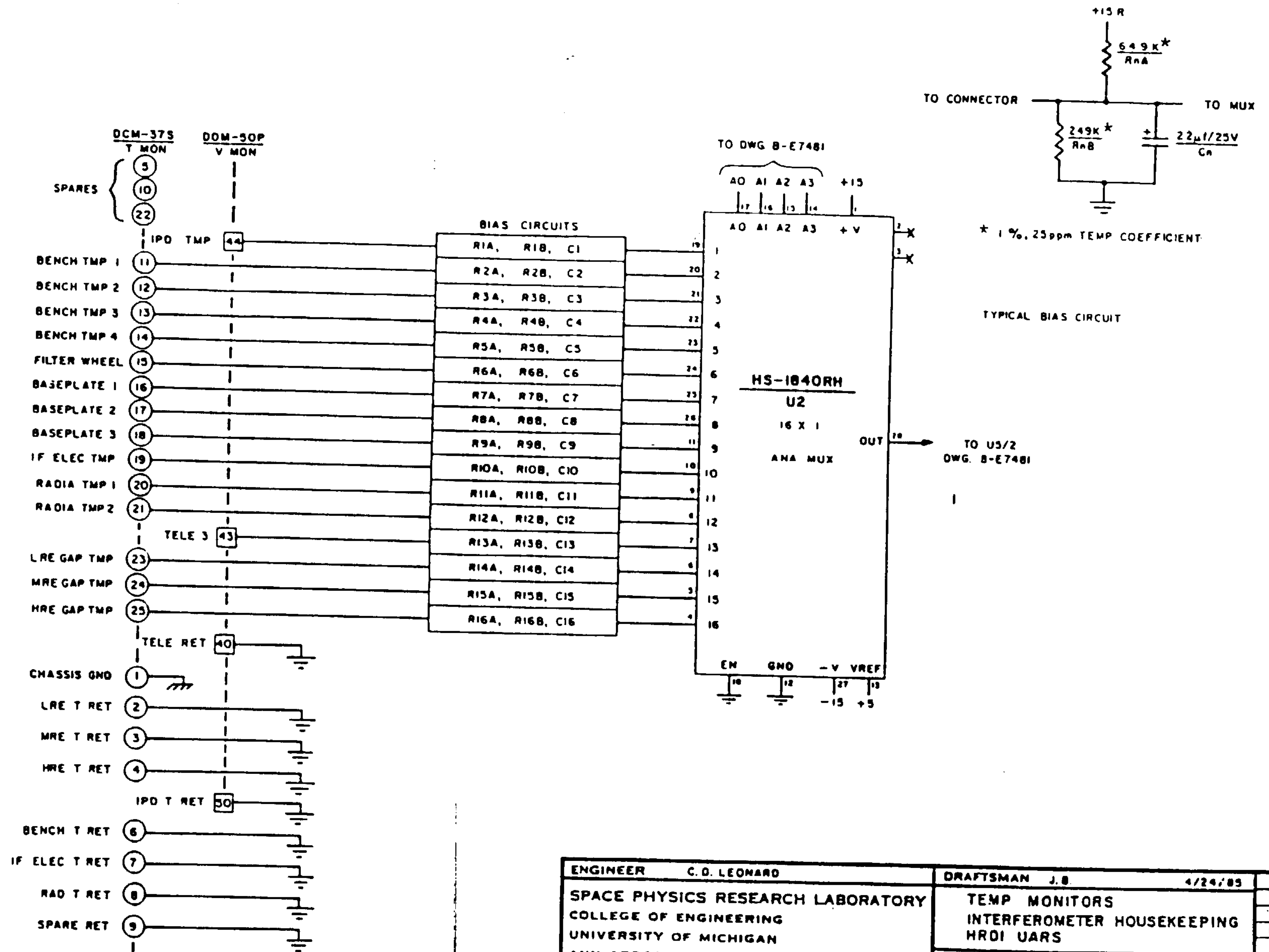

ENGINEER C.D. LEONARD	DRAFTSMAN J.B. 4/24/85	
SPACE PHYSICS RESEARCH LABORATORY COLLEGE OF ENGINEERING UNIVERSITY OF MICHIGAN ANN ARBOR, MICHIGAN	TEMP MONITORS INTERFEROMETER HOUSEKEEPING HRDI UARS	8/21/86 1/6/86
	B-E7439 CONTROLLED	DATE

LAST USED R16 C16 D L

23.3

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Power Distribution

- Preliminary

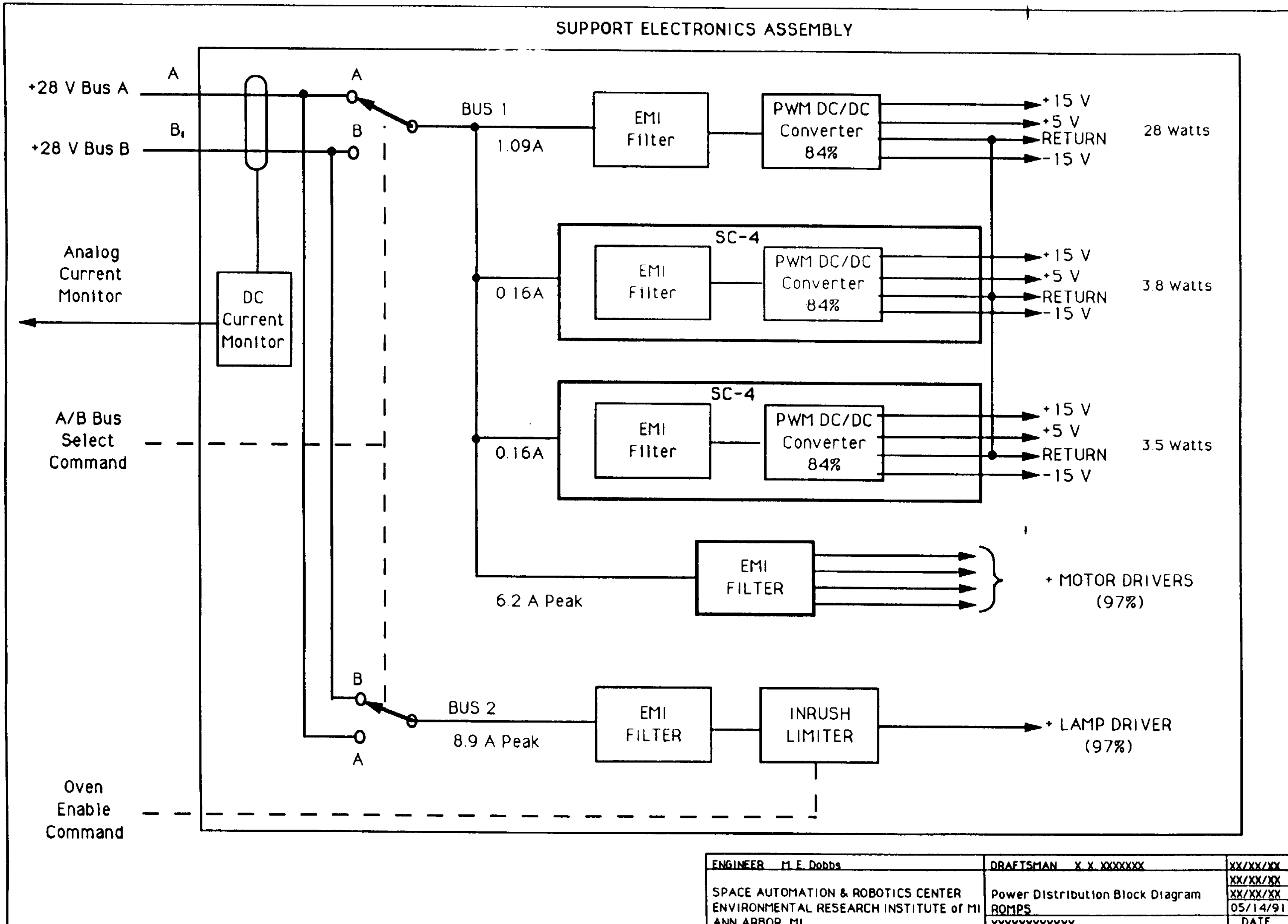
- Issues

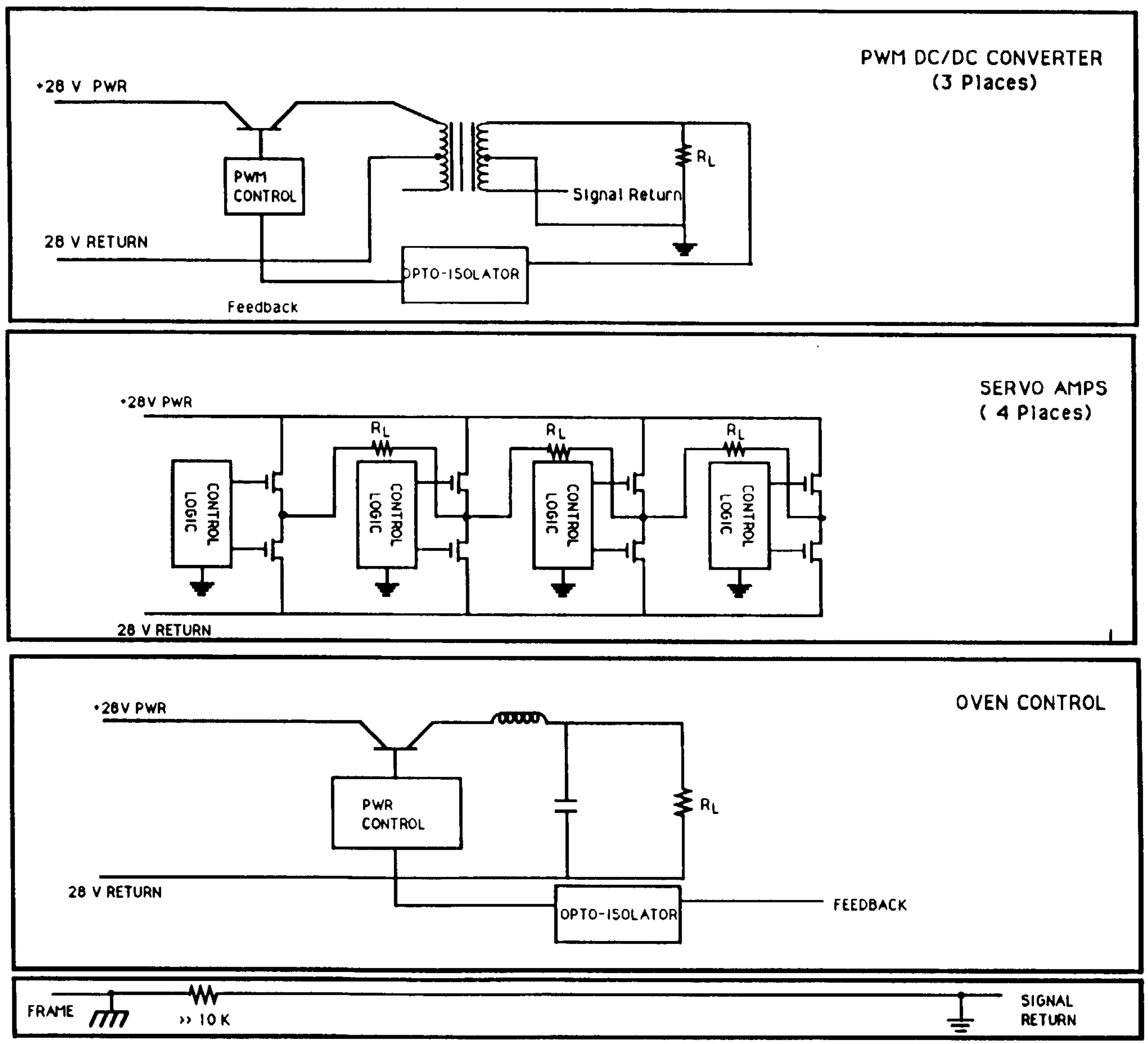
  Run servo's off +28 Bus

  w/ isolation by opto on FET gates

TODO

~~Star point~~ True gnd diagram


SUPPORT ELECTRONICS ASSEMBLY
+28 V Bus A
+28 V Bus B
A
B1
Analog Current Monitor
DC Current Monitor
A/B Bus Select Command
Oven Enable Command
A
B
BUS 1
1.09A
EMI Filter
PWM DC/DC Converter 84%
+15 V
+5 V
RETURN
-15 V
28 Watts
SC-4
0.16A
EMI Filter
PWM DC/DC Converter 84%
+15 V
+5 V
RETURN
-15 V
3.8 Watts
SC-4
0.16A
EMI Filter
PWM DC/DC Converter 84%
+15 V
+5 V
RETURN
-15 V
3.5 Watts
6.2 A Peak
EMI FILTER
+ MOTOR DRIVERS (97%)
B
A
BUS 2
8.9 A Peak
EMI FILTER
INRUSH LIMITER
+ LAMP DRIVER (97%)
ENGINEER M. E. Dobbs
SPACE AUTOMATION & ROBOTICS CENTER
ENVIRONMENTAL RESEARCH INSTITUTE of MI
ANN ARBOR, MI
DRAFTSMAN X. X. XXXXXXX
Power Distribution Block Diagram
ROMPS
XXXXXXXXXXXX
XX/XX/XX
XX/XX/XX
XX/XX/XX
05/14/91
DATE



ENGINEER L. M. Tomko	DRAFTSMAN X. X. XXXXXXX	XX/XX/XX
	Grounding Diagram	XX/XX/XX
SPACE AUTOMATION & ROBOTICS CENTER	Power Distribution Block Diagram	XX/XX/XX
ENVIRONMENTAL RESEARCH INSTITUTE of MI	RoMPS	05/14/91
ANN ARBOR, MI	XXXXXXXXXXXX	DATE

17.1

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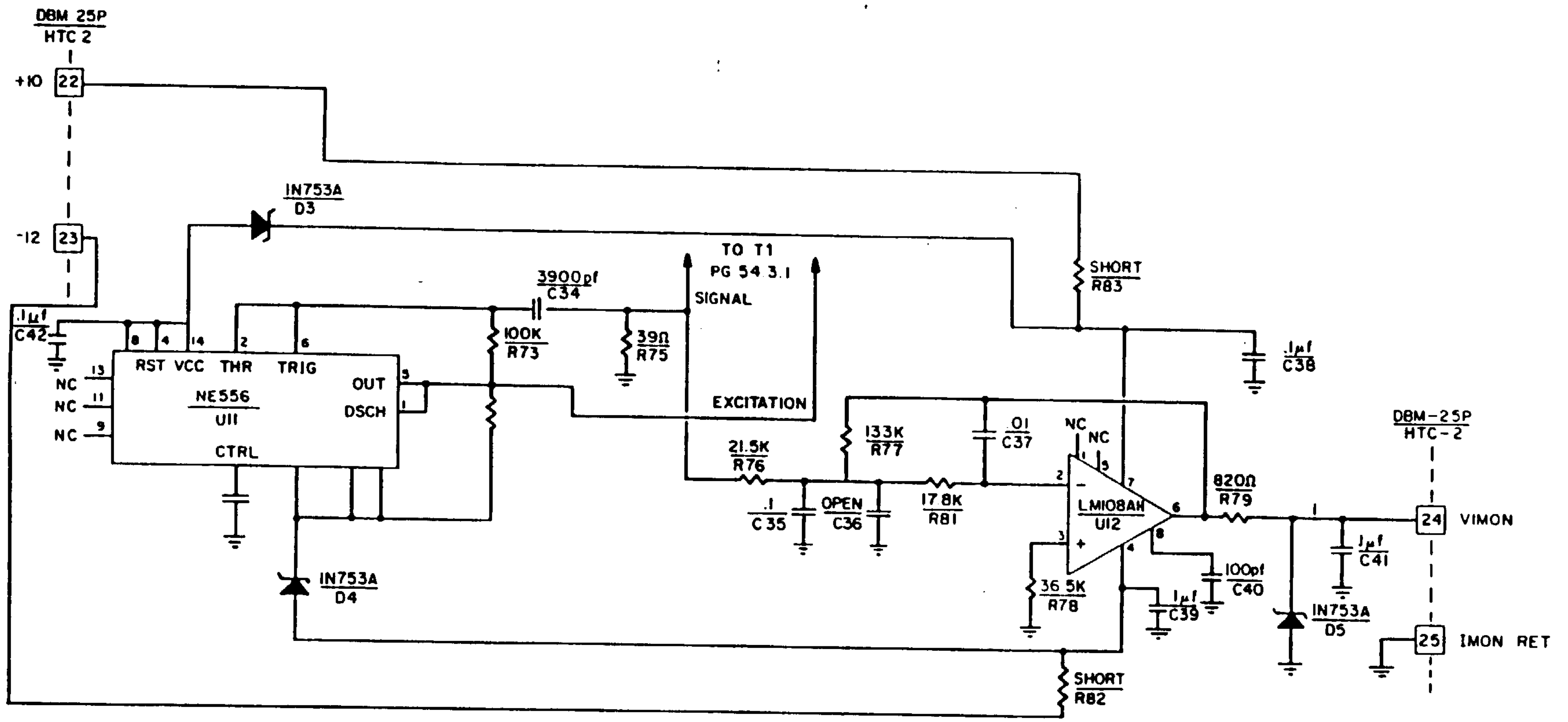
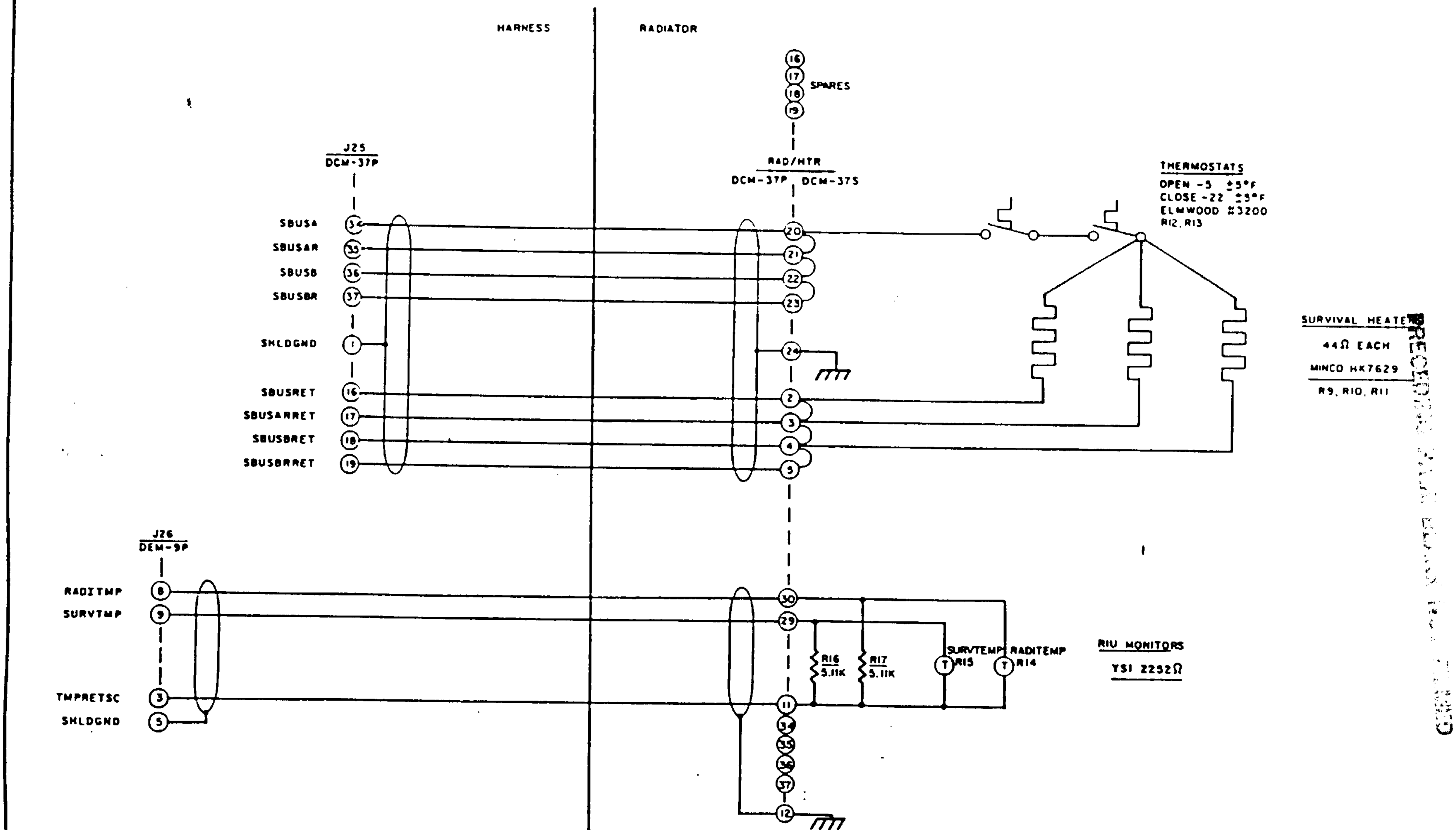


NOTE:

1) NE556 VCC@ 10-6.2=3.8
GND@ -12+6.2=5.8
9.6 TOTAL

ENGINEER J. STEVENS D. BOPRIE	DRAFTSMAN R.K. 6/15/88	
SPACE PHYSICS RESEARCH LABORATORY COLLEGE OF ENGINEERING UNIVERSITY OF MICHIGAN ANN ARBOR, MICHIGAN	IMON HTC HRDI UARS	2/1/89 7/15/88
	B-E8376 CONTROLLED	DATE

LAST USED R C D L



ENGINEER M. E. DOBBS

SPACE PHYSICS RESEARCH LABORATORY
COLLEGE OF ENGINEERING
UNIVERSITY OF MICHIGAN
ANN ARBOR, MICHIGAN

DRAFTSMAN R.K. J.B. 8/26/87

RADIATOR WIRING
INTERFEROMETER
HRDI UARS
PAGE 2 OF 2

B-E8272 CONTROLLED

7/15/
7/6/
5/27/
DATE

LAST USED R C D L

KOE 10 1153 2/06 1140Y

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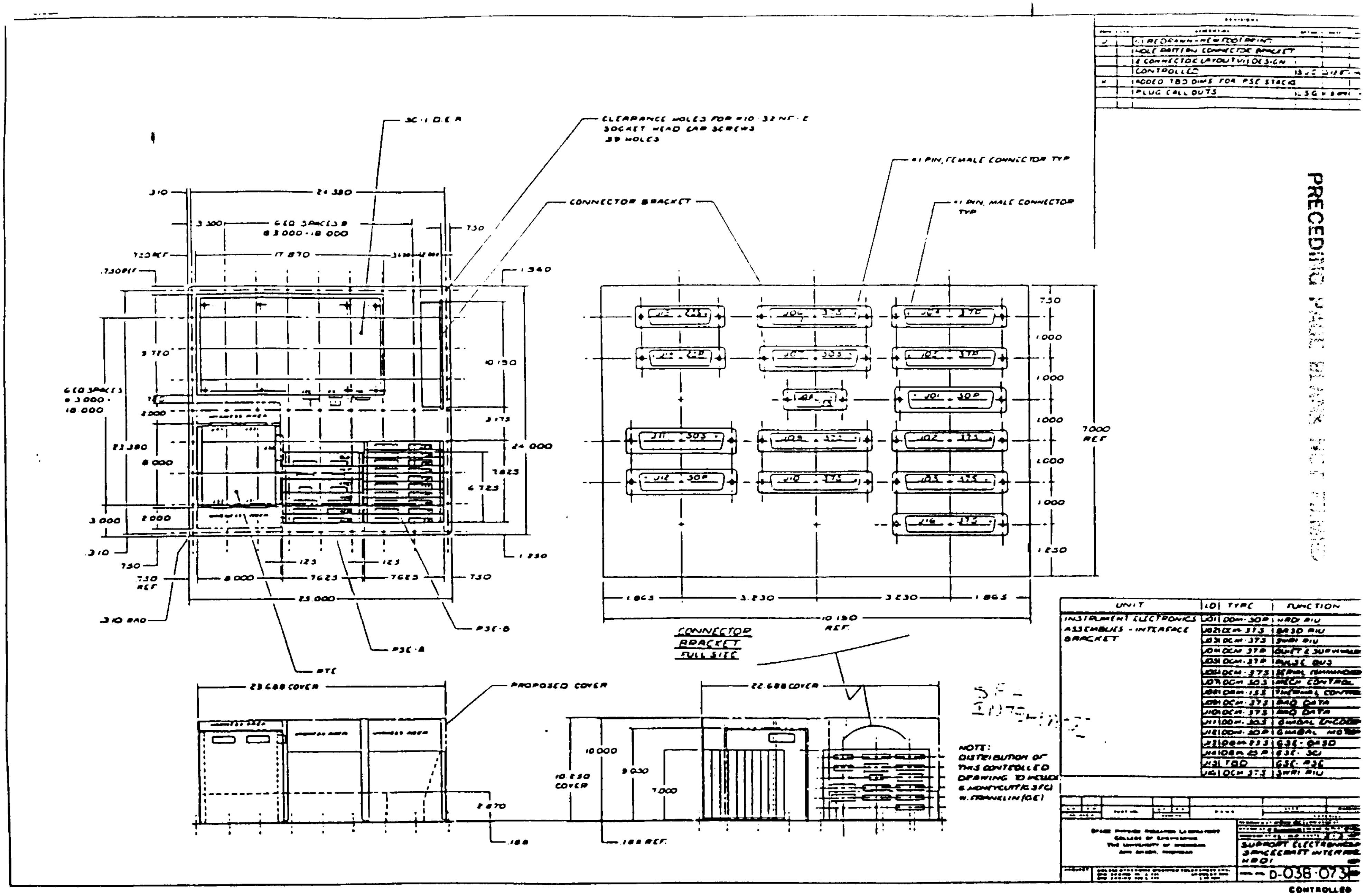
Space Physics Research Laboratory
Packaging Conventions

STD Aluminum Frame
Provides robust pkg - flight history
inexpensive, reliable

Goal - minimize packaging effort


CLEARANCE HOLES FOR #10-32 NF-2 SOCKET HEAD CAP SCREWS 39 HOLES
CONNECTOR BRACKET
PIN, FEMALE CONNECTOR TYP
PIN, MALE CONNECTOR TYP
PSE-B
PSE-A
RTC
PROPOSED COVER
23.688 COVER
22.688 COVER
10.250 COVER
CONNECTOR BRACKET FULL SIZE
7.000 REF
10.150 REF
NOTE: DISTRIBUTION OF THIS CONTROLLED DRAWING TO INCLUDE E. MONTYCUTT (GSFC) W. FRANKLIN (GE)
UNIT
TYPE
FUNCTION
INSTRUMENT ELECTRONICS ASSEMBLIES - INTERFACE BRACKET
SUPPORT ELECTRONICS SPACECRAFT INTERFACE
D-038-073
CONTROLLED

Interim Design Review

NASA Goddard Space Flight Center
Robotic Material Processing System Program
Automation Systems

18 October 1991

prepared by

Environmental Research Institute of Michigan
Space Automation and Robotics Center
P.O. Box 134001
Ann Arbor, Michigan 48113-4001

RoMPS General Mission Requirements

- Rapid Thermal Annealing (RTA) in Microgravity
  - Microgravity material processing
  - High temperature annealing furnace
  - Automated RTA processing and sample change

- STS Hitchkiker Payload
  - GAS canister and HH avionics mounting plate
  - Class D payload classification
  - Serial command and telemetry

- Mission Characteristics
  - Operates during STS disturbance free "quiet" periods
  - Operational changes expected
    - reschedule operations to meet STS constraints
    - modification of RTA processing parameters

Office of Commercial Programs Requirements

- Infrastructure - Enable Low Cost Space Manufacturing
  - new technology - patents, license, product sales
  - reduced cost-per-pound
    - reduce non-recurring engineering cost
    - use industrial practices and products
    - carrier independent systems
    - experiment independent systems
  - system architecture for manufacturing facility

- Closely Related OCP Infrastructure CCDS Flight Programs at SpARC
  - Autonomous Rendezvous & Docking
    - Autonomous Experiment Mangement System (AEMS)
  - Wake Shield Facility
    - Autonomous Experiment Mangement System (AEMS)
    - Robotic Substrate Servicing System
    - Satellite Servicing System
    - EPOP Control and Data System (AEMS)
  - LABS
    - Autonomous Experiment Mangement System (AEMS)
    - Material Handling Automation

Automation Management System

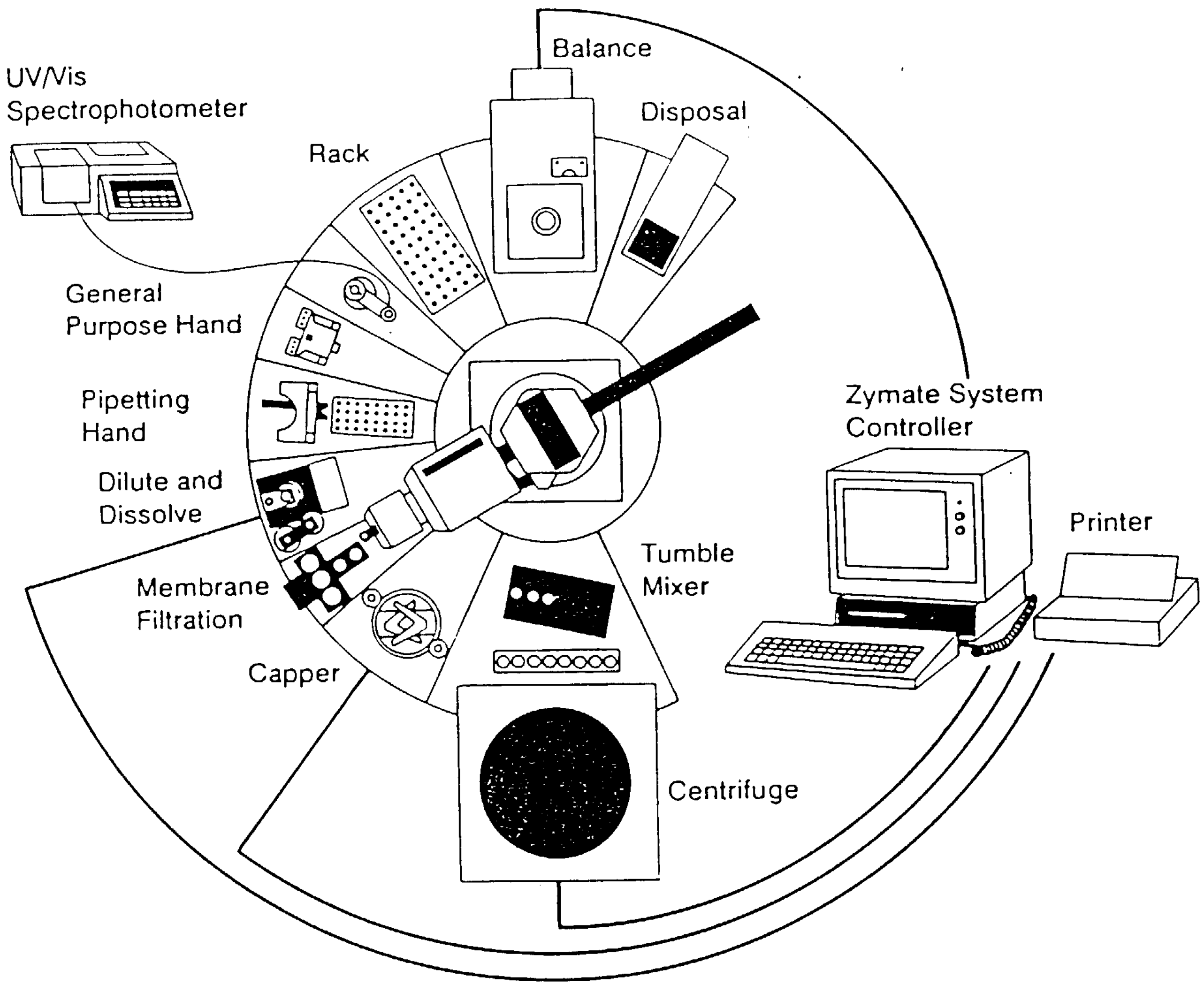
- Schedule Scripts
  - STS operational timeline changes
  - Investigator sample priority changes

- Processing Scripts
  - process methodology changes
  - process parameter changes

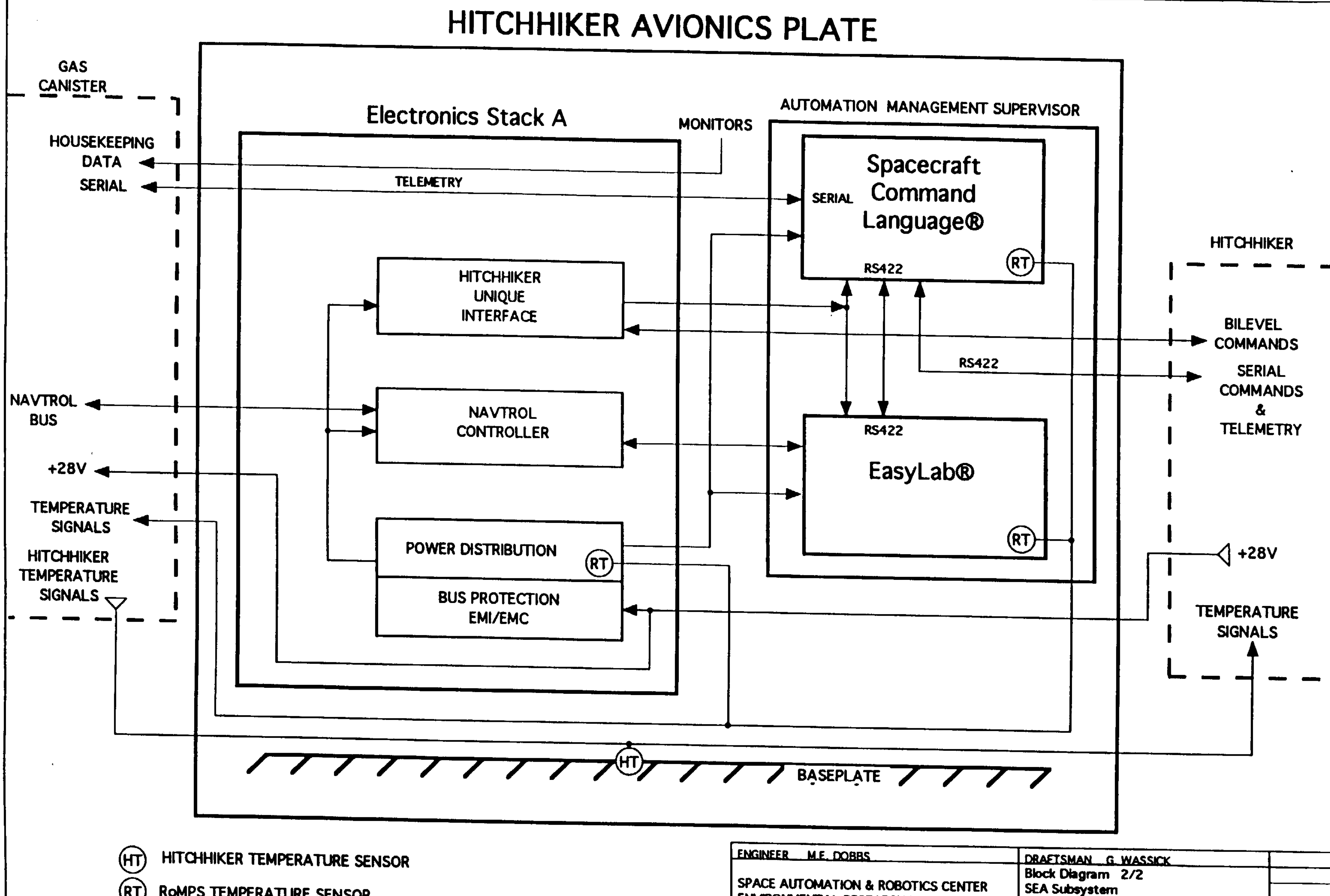
- High Level Language User Interface
  - industry proven
  - put PI in the drivers seat
  - attempt transparent environment from laboratory to flight

- Automatic Control
  - automatic sample change
  - automatic process control
  - rule based error detection and resolution

5


Balance
UV/Vis Spectrophotometer
Disposal
Rack
General Purpose Hand
Pipetting Hand
Zymate System Controller
Dilute and Dissolve
Printer
Tumble Mixer
Membrane Filtration
Capper
Centrifuge

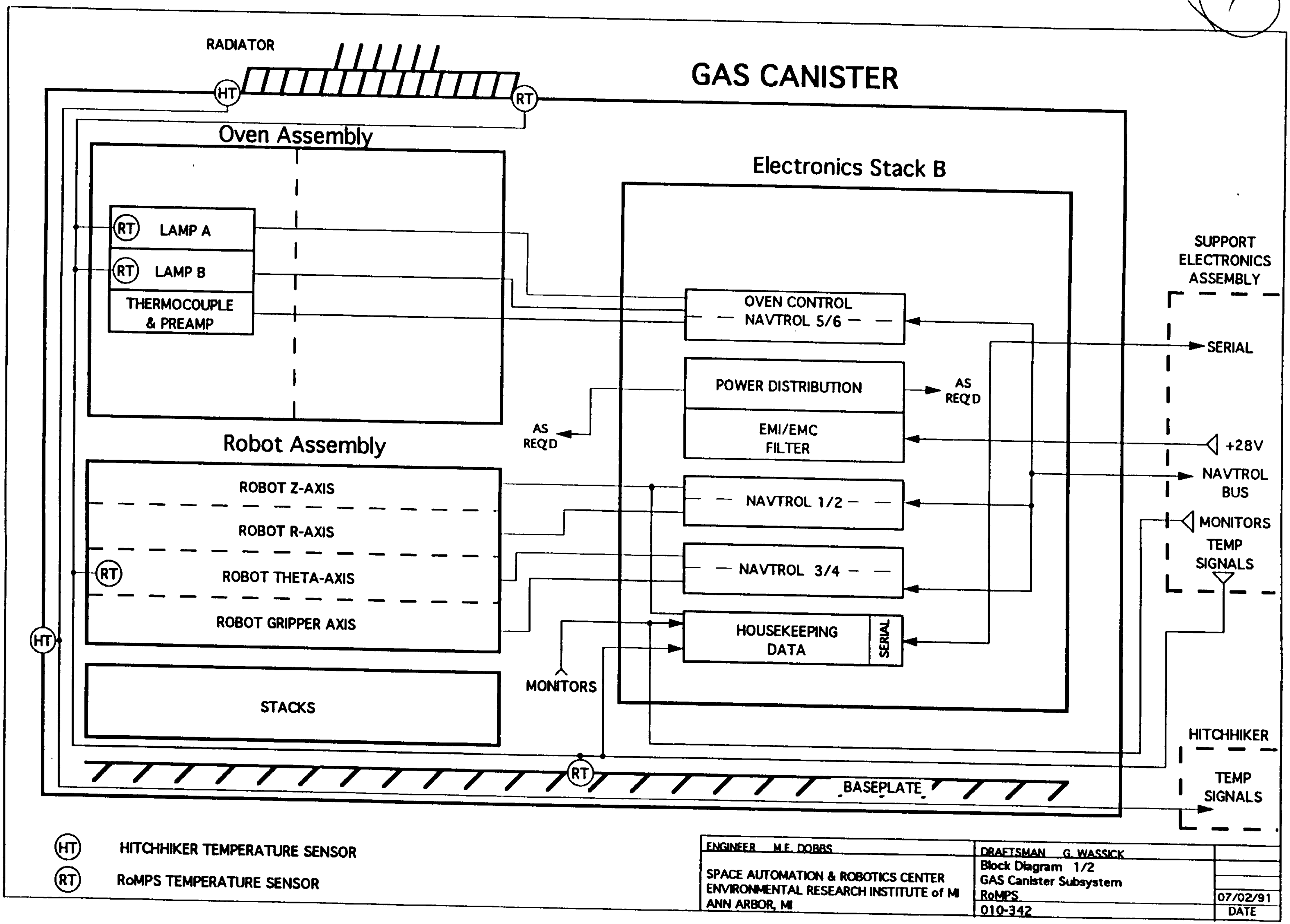
6



ENGINEER M.E. DOBBS	DRAFTSMAN G. WASSICK	
SPACE AUTOMATION & ROBOTICS CENTER ENVIRONMENTAL RESEARCH INSTITUTE of MI ANN ARBOR, MI	Block Diagram 2/2 SEA Subsystem RoMPS 010-339	07/02/91 DATE

1.2.2

7


GAS CANISTER
RADIATOR
Oven Assembly
LAMP A
LAMP B
THERMOCOUPLE & PREAMP
Robot Assembly
ROBOT Z-AXIS
ROBOT R-AXIS
ROBOT THETA-AXIS
ROBOT GRIPPER AXIS
STACKS
Electronics Stack B
OVEN CONTROL
NAVTROL 5/6
POWER DISTRIBUTION
EMI/EMC FILTER
NAVTROL 1/2
NAVTROL 3/4
HOUSEKEEPING DATA
SERIAL
AS REQ'D
AS REQ'D
MONITORS
BASEPLATE
SUPPORT ELECTRONICS ASSEMBLY
SERIAL
+28V
NAVTROL BUS
MONITORS
TEMP SIGNALS
HITCHHIKER
TEMP SIGNALS
HT HITCHHIKER TEMPERATURE SENSOR
RT RoMPS TEMPERATURE SENSOR
ENGINEER M.E. DOBBS
SPACE AUTOMATION & ROBOTICS CENTER
ENVIRONMENTAL RESEARCH INSTITUTE of MI
ANN ARBOR, MI
DRAFTSMAN G. WASSICK
Block Diagram 1/2
GAS Canister Subsystem
RoMPS
010-342
07/02/91
DATE

1.2.1

8

SCL Scripts

- SCL scripts are similar to tasks or other stand alone programs.
- Scripts can be executed immediately by command directive.
- Scripts can also be scheduled for deferred execution. SCL supports:
    - Absolute execution times.
    - Relative execution times.
- Scripts can be scheduled for cyclic execution (repetitive execution).

Experiment Spreadsheet

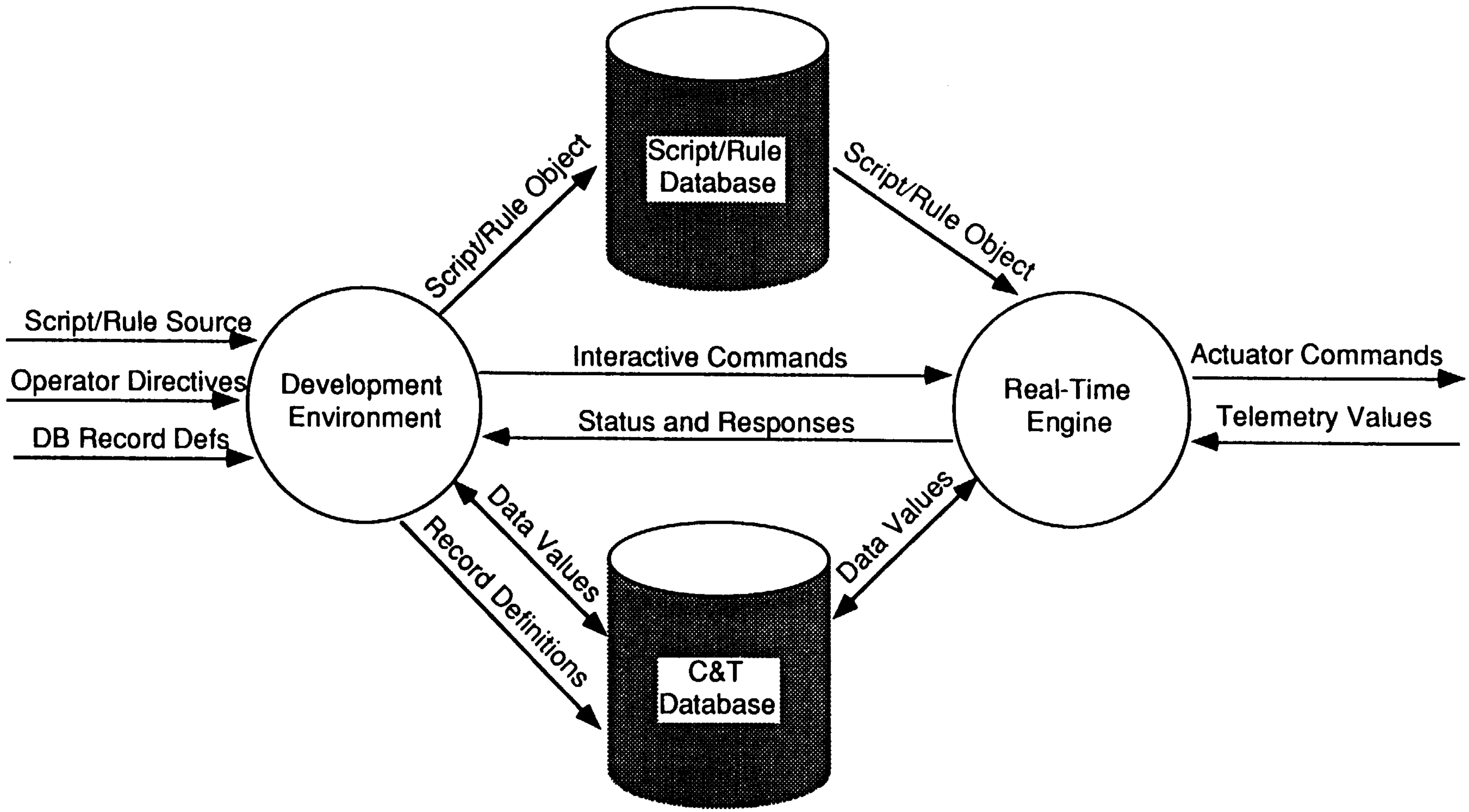
	A	B	C	D	E	F	G	H	I
1	Run	Sample	Rack	Rack Index	Temperature 1	Time 1	Temperature 2	Time 2	Processed
2	1	1	1	1	410	90	410	90	N
3	2	2	1	2	410	90	410	90	N
4	3	3	1	3	410	90	410	90	N
5	4	4	1	4	410	90	410	90	N
6	5	5	1	5	410	90	410	90	N
7	6	6	1	6	410	90	410	90	N
8	7	7	1	7	350	90	350	90	N
9		...	...	...	...	...	...	...	...
10		...	...	...	...	...	...	...	...
11		...	...	...	...	...	...	...	...
12		...	...	...	...	...	...	...	...
13	141	141	6	5	400	30	400	30	N
14	142	142	6	6	200	30	200	30	N
15	143	143	6	7	400	5	400	5	N
16	144	144	6	8	400	15	400	15	N

```
-- SCL Scenario Script
--
-- Function Defines processing scenario for do_processing
-- script.

script experiment_scenario

run                     = 1
gSample[run]            = 1
gRack[run]              = 1
gRack_Index[run]        = 1
gTemperature1[run]      = 410
gTime1[run]             = 90
gTemperature2[run]      = 410
gTime2[run]             = 90

run                     = 2
gSample[run]            = 2
gRack[run]              = 1
gRack_Index[run]        = 2
gTemperature1[run]      = 410
gTime1[run]             = 90
gTemperature2[run]      = 410
gTime2[run]             = 90

    ...

    ...
run                     = 144
gSample[run]            = 144
gRack[run]              = 6
gRack_Index[run]        = 8
gTemperature1[run]      = 200
gTime1[run]             = 30
gTemperature2[run]      = 200
gTime2[run]             = 30

end experiment_scenario
```

SCL Software Components

- The SCL software system is divided into 3 major components:
  - The Development Environment. The development environment provides tools for developing and maintaining scripts and rules and for controlling the operation of the system
  - The Real-Time Database. The database defines the SCL software's operating environment.
  - The Real-Time Engine (RTE). Executes the SCL scripts, rules, and command directives.

SCL Software Data Flows



SCL Real-Time Engine

- The Real-Time Engine (RTE) executes SCL scripts, rules and command directives.
- The RTE is portable:
  - Written in C and Ada
  - Application specific I/O and system service calls have been isolated and "abstracted" out the SCL software.
- The RTE is generic/reusable. SCL scripts and rules are used to tailor the system to a specific application.
- The RTE is dynamic. Scripts and rules can be added or deleted without changing the RTE and its underlying interface routines.

RoMPS EasyLab Command &Variable Summary for Rack Stations

RACK.INDEX	EasyLab variable used by RoMPS PyTechnology to determine the current sample for robot to manipulate. Initial Value is 1.
GET.FROM.RACK	Get sample RACK.INDEX from its home rack and slot.
PUT.INTO.RACK	Move the currently held sample into the home rack and slot of RACK.INDEX.

RoMPS EasyLab Command &Variable Summary for Annealer Module

ANNEALER.TEMPERATURE	Output Command Variable used to set the target temperature for the next annealing initiated by ANNEALER.ON and ANNEALER.TIMED.RUN. Initial Value TBD.
ANNEALER.TIME	Output Command Variable used to set the annealing time for the next annealing initiated by ANNEALER.TIMED.RUN. Initial Value TBD.
ANNEALER.RATE	Output Command Variable used to set the heating rate for the next annealing initiated by ANNEALER.ON and ANNEALER.TIMED.RUN. Initial Value TBD.
ANNEALER.ACTIVE.OVEN	EasyLab variable used by the Annealer robot movent commands, to determine position to put and get samples.
MOVE.UNDER.ANNEALER	Move Robot Gripper Under Sample, Lined up to allow pallet to be inserted into annealer.
PUT.INTO.ANNEALER	Move sample up into Annealer After a MOVE.UNDER.ANNEALER command.
ANNEALER.ON	Initiate an untimed run of the Annealer.
ANNEALER.OFF	Terminate an untimed run of the Annealer.
ANNEALER.TIMED.RUN	Initiate a timed run of the Annealer.

16

Automation Management System

- Architecture Demonstrated at SpARC on 4 October 1991

  SC4 #1 with SCL implements
  - generic - scheduler
  - specific - carrier i/o

  SC4 #2 with EASYLAB implements
  - generic - sample handling, processing
  - specific - robot geometry

  Electronics
  - generic - servos, housekeeping
  - specific - interfaces

- Status
  MOU's in place
  License agreements outlined
  DFD's prepared
  Elements to be designed have models to work from

- Long Term Architecture
  Multiple robot and process space manufacturing facility

- Minimize Lifecycle Costs
  Industrial development, support, maintenance and documentation

RoMPS Electronics Assemblies

- Support Electronics Assembly

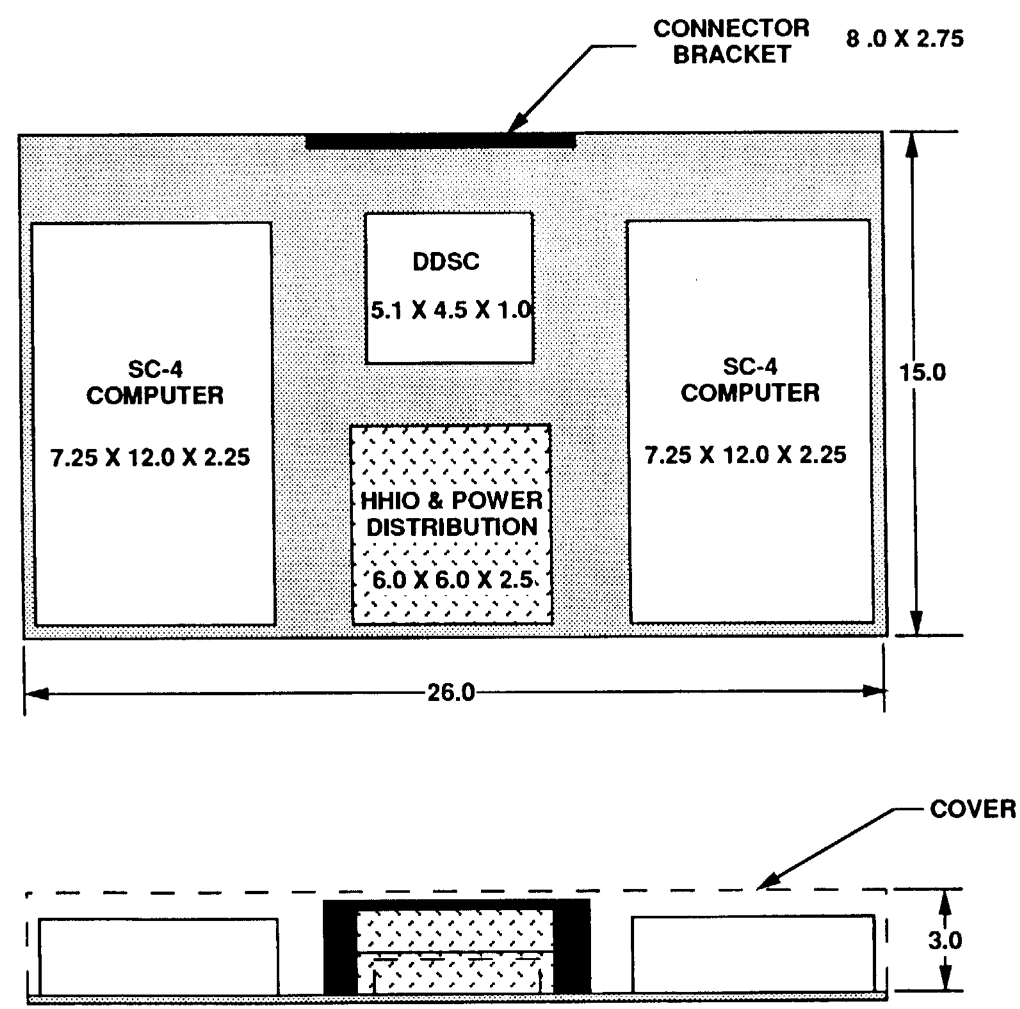
    Mounted to Hitchhiker Adapter Plate
    Integrated assembly with common support plate and cover
        Connector Bracket
        Power Distribution
        SwRI SC4 Computer #1
        SwRI SC4 Computer #2
        Navtrol DDSC Master

- GAS Electronics Assembly

    Mounted inside 5" GAS Extension
    Integrated assembly with common support plate
        Connector Brackets
        Power Distribution
        Navtrol DDSC Slave #1
        Navtrol DDSC Slave #2
        Navtrol DDSC Slave #3
        Thermocouple Signal Conditioning
        Data Acquisition

18

SUPPORT ELECTRONICS ASSEMBLY



ENGINEER R.E. QUADA	DRAFTSMAN S.J. CARR	
SPACE AUTOMATION & ROBOTICS CENTER ENVIRONMENTAL RESEARCH INSTITUTE of MI ANN ARBOR, MI	LAYOUT SUPPORT ELECTRONICS ASSEMBLY ROMPS	10/09/91 DATE

19

20

	A	B	C	D	E	F	G	H
1	RoMPS Weight & Power							
2	Assembly	Subassembly	Mfgr	Size LWH in	Mass lbs	Avg Pwr	Peak Pwr	Comments
3								
4	Support Elect	mount plate	GSFC		tbd			
5	Assembly	emi cover	GSFC		tbd			
6		SC-4	SwRI	7.25x12.25x2	3.7	5	5	
7		SC-4	SwRI	7.25x12.25x2	3.7	5	5	
8		HH I/O	ERIM	7 x 7 x 0.75	1.1	1	1	
9		HH PWR	ERIM	7 x 7 x 1.25	1.1	0	0	
10		DDSC Master	Navtrol	4.5x5.1x1	2	3.7	3.7	
11		connec. brack	ERIM		tbd			
12		harness	ERIM		tbd			
13		hardware			tbd			
14								
15		SUBTOTAL			11.6	14.7		
16								
17	GAS Eectroni	mount plate	GSFC	17.5 dia	tbd			
18	Assembly	DDSC	Navtrol	4.5x5.1x1	2	3.7	269	9.6a worst ca
19		DDSC	Navtrol	4.5x5.1x1	2	3.7		one axis only
20		DDSC	Navtrol	4.5x5.1x1	2	3.7		one axis only
21		Housekeeping	ERIM	7x7x0.75	1.1	3	5	logic
22		Housekeeping	ERIM	7x7x0.75	1.1	2	5	analog
23		Power Dist	ERIM	7x7x1.25	2.2	2	2	converter los
24		connec.bracke	ERIM		tbd			
25		harness	ERIM		tbd			
26		hardware			tbd			
27								
28		SUBTOTAL			10.4	18.1		
29								
30		TOTAL			22	32.8		

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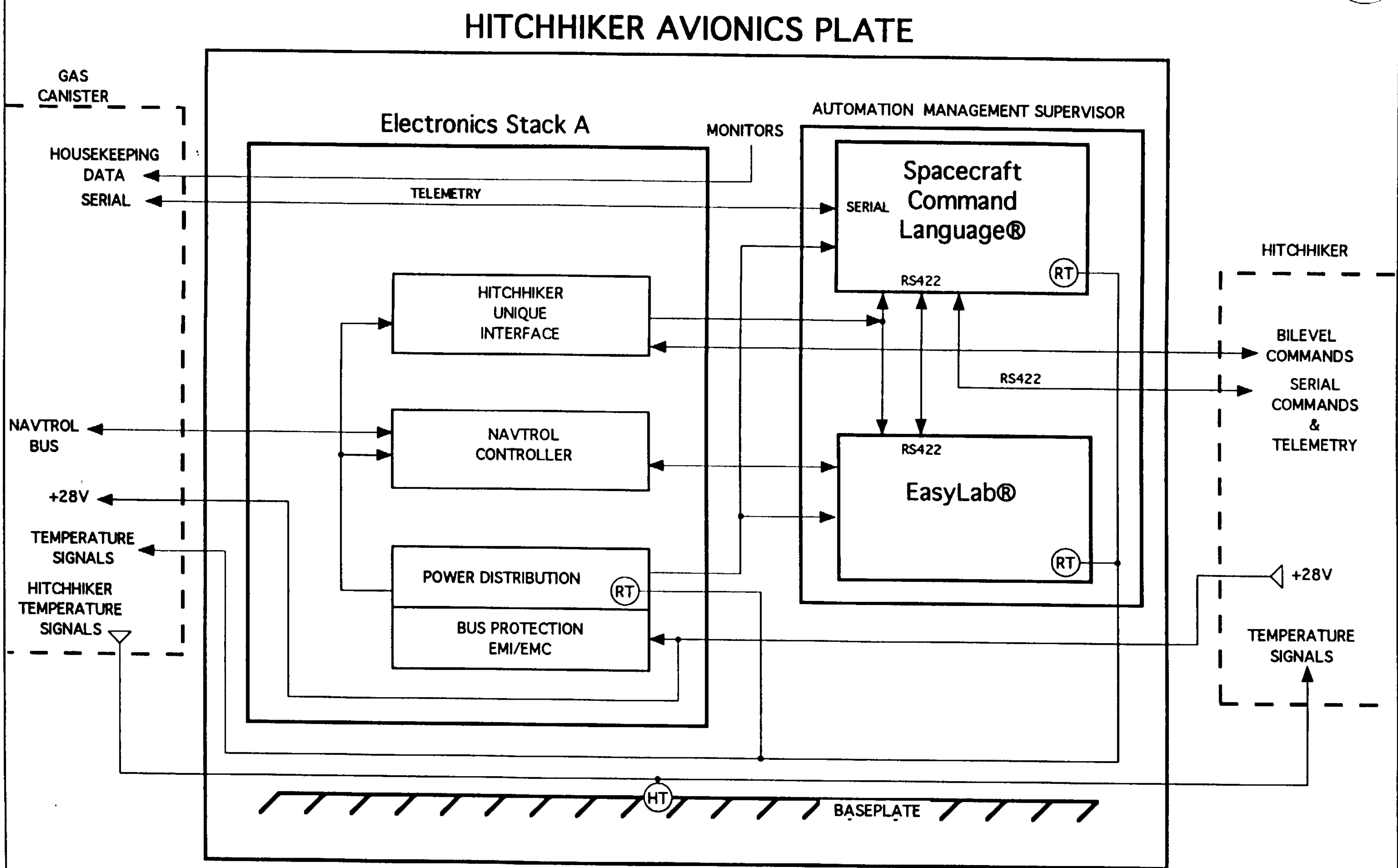
C-2

20A



(HT) HITCHHIKER TEMPERATURE SENSOR

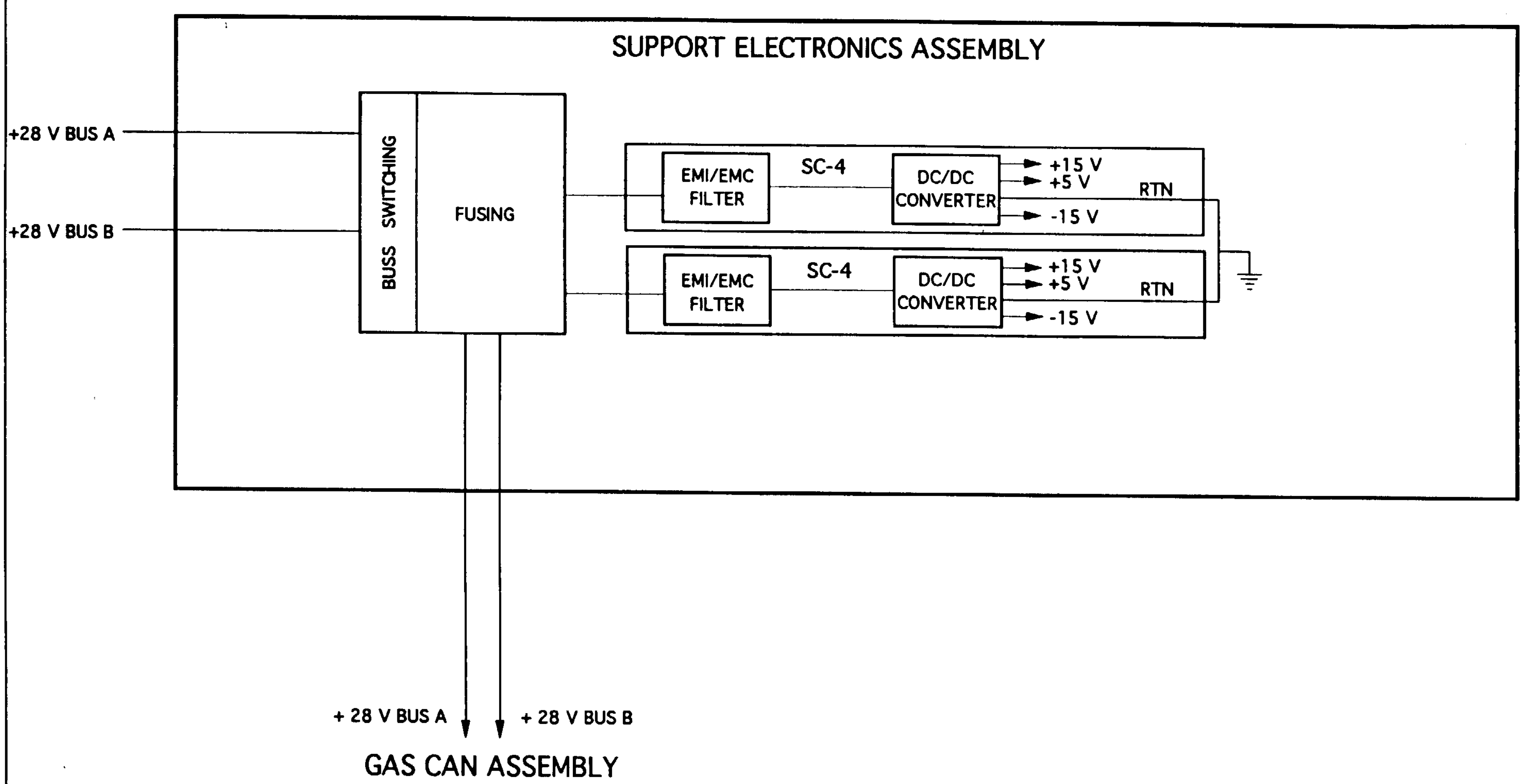
(RT) RoMPS TEMPERATURE SENSOR

ENGINEER M.E. DOBBS	DRAFTSMAN G. WASSICK	
SPACE AUTOMATION & ROBOTICS CENTER ENVIRONMENTAL RESEARCH INSTITUTE of MI ANN ARBOR, MI	Block Diagram 2/2 SEA Subsystem RoMPS 010-339	07/02/91 DATE

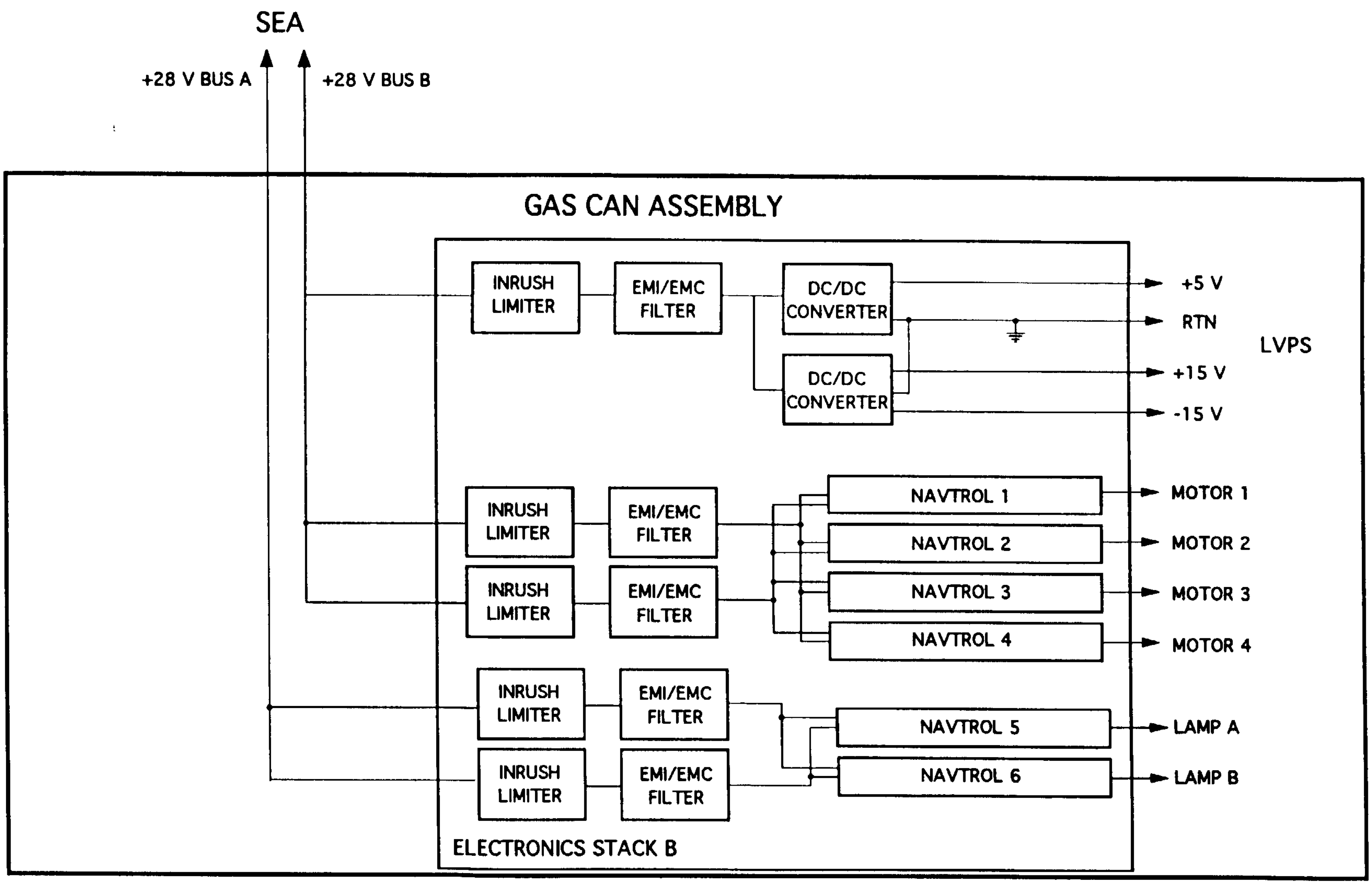
Hitchhiker Interface Subsystem

- Flight Hardware
  - power switching and bus protection
  - serial interface receivers and drivers
  - HH command packet protocol processing
  - telemetry packet generation
  - health and safety monitors

- Ground Support Equipment & Operations Console
  - customer ground support equipment
    - command generation
      - script development
      - process development
    - telemetry processing
      - archiving
      - engineering unit conversion
      - parameter limit checking
  - investigator operations console

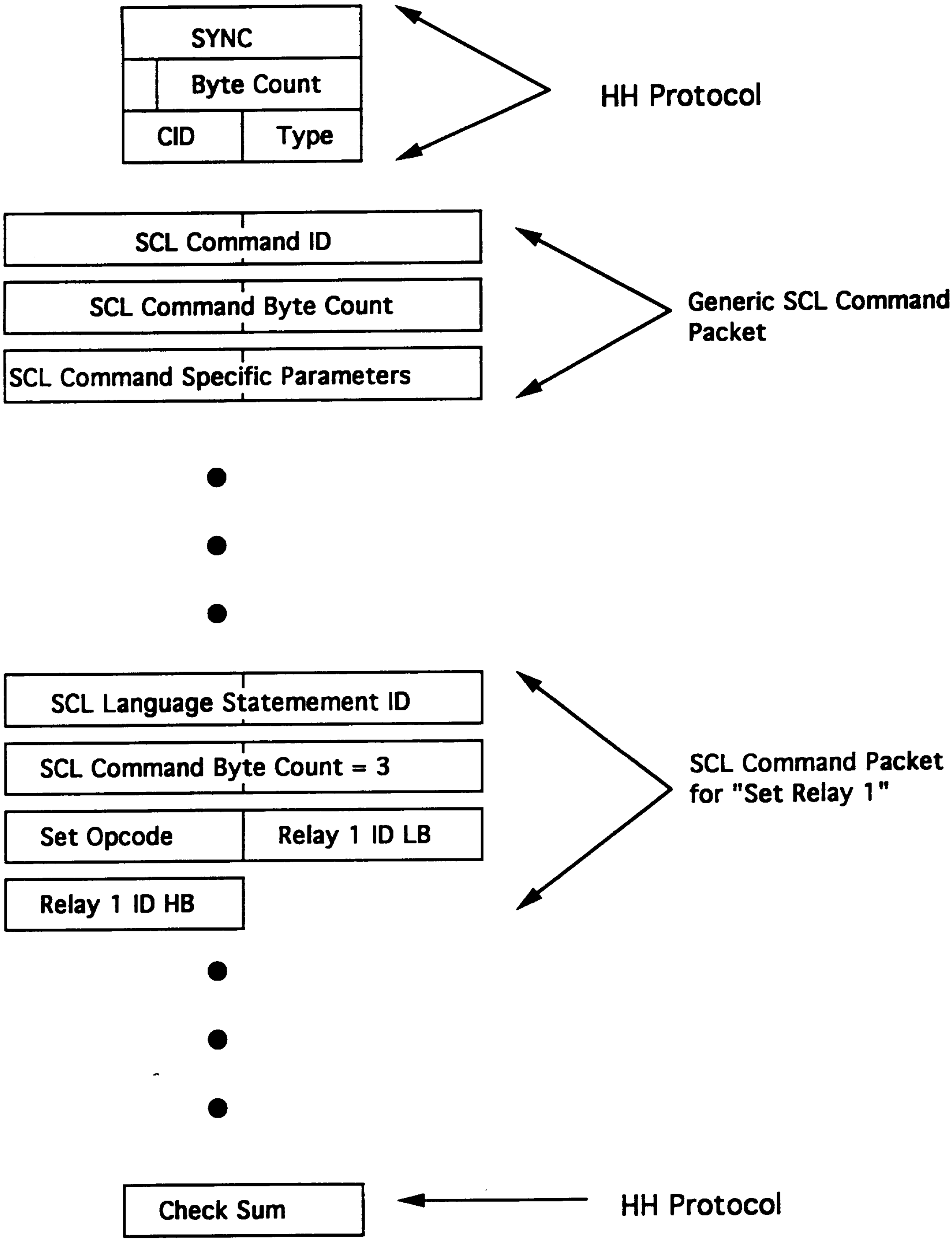


ENGINEER M. E. Dobbs	DRAFTSMAN	
SPACE AUTOMATION & ROBOTICS CENTER ENVIRONMENTAL RESEARCH INSTITUTE of MI ANN ARBOR, MI	SEA Power Distribution Block Diagram ROMPS	10/10/91 05/14/91
	010-341	DATE



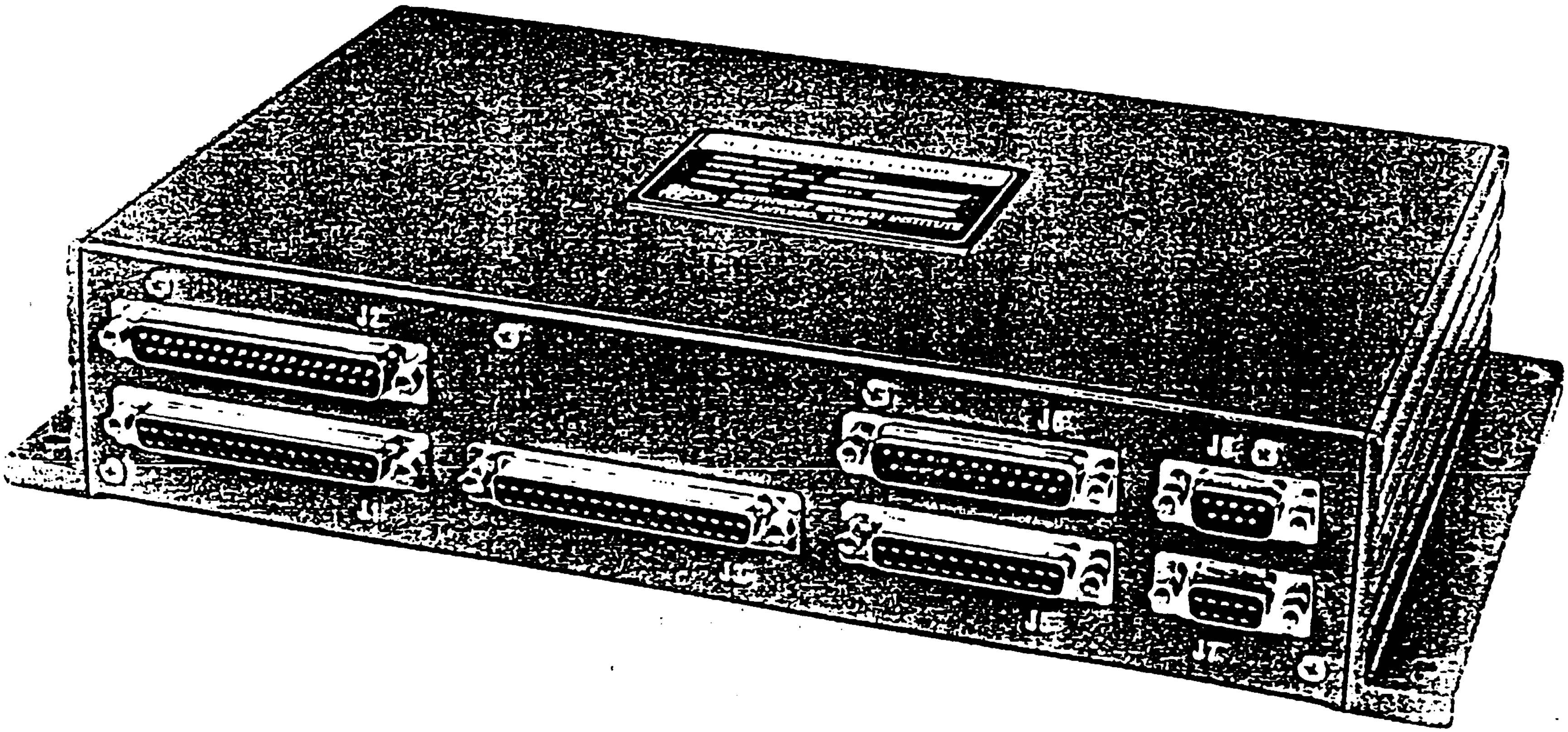
ENGINEER M.F.DOBBS	DRAFTSMAN	
SPACE AUTOMATION & ROBOTICS CENTER ENVIRONMENTAL RESEARCH INSTITUTE of MI ANN ARBOR, MI	GAS Can Assembly Power Distribution Block Diagram RoMPS 010-345	10/10/92 07/17/91 DATE

SCL Uplink Packet Definition



	A	B	C	D	E
1	**RoMPS Telemetry**				
2	**Function**	**Description**	**Length**	**Rate**	**Comment**
3					
4	Frame Header	sync	2	1	
5		sync/id	2	1	
6					
7	RTE Packet	id, etc	2	1	
8		rte state	2	1	
9		agenda status	2	1	
10		script status	10	1	
11		script status	10	1	
12					
13	DUMP Packet	id/len	4	1	
14		sample id	2	1	
15		process id	2	1	
16		sample temp	2	1	
17		lamp intensit	2	1	
18		lamp intensit	2	1	
19		lamp intensit	2	1	
20		lamp intensit	2	1	
21		lamp current	2	1	
22		elevation	2	1	
23		theta	2	1	
24		radial	2	1	
25		grip	2	1	
26		force	2	1	
27		exp. current	2	1	
28		eot status	2	1	
29		error reports	10	1	5 maximum
30		housekeeping	16	1	8 maximum
31					
32	TOTAL		90		
33	BUDGET		120		1200 baud

26



ENGINEER	DRAFTSMAN	
SPACE AUTOMATION & ROBOTICS CENTER ENVIRONMENTAL RESEARCH INSTITUTE of MI ANN ARBOR, MI	010-132	08/08/91 DATE

TABLE 1.2.2-1

Preliminary Specification
SC-4 Single Board Spacecraft Computer

Central Processor	80C186/80C187 16 Bit
Clock Frequency	10 MHz
Operating System	MS-DOS and VRTX Compatible
Onboard Memory	
RAM	512K Bytes w/EDC
EEPROM	256K Bytes w/EDC
UVPROM	640K Bytes w/EDC
Hardware Vectored Interrupts	16 User Configurable
Timer/Event Counters	8, Software Configurable, 120 ns Granularity
Input/Output Capability	
Parallel I/O	16 Input, 16 Output
Analog Input	32 Channels, 12-bit Resolution
Analog Output	4 Channels, 12-bit Resolution
RS-422 Serial I/O	2 Channels
SCSI Interface	1 Port
Software Controlled Power Switch	4 Each
Mass Storage	24M Bytes, Read/Write Non-volatile with Additional Battery
Expansion	Internal Daughterboard Connector
Size	7.25 X 12 X 2.25 in
Weight	3.7 Lb (Approximate)
Power	28v @ 5w (Approximate)

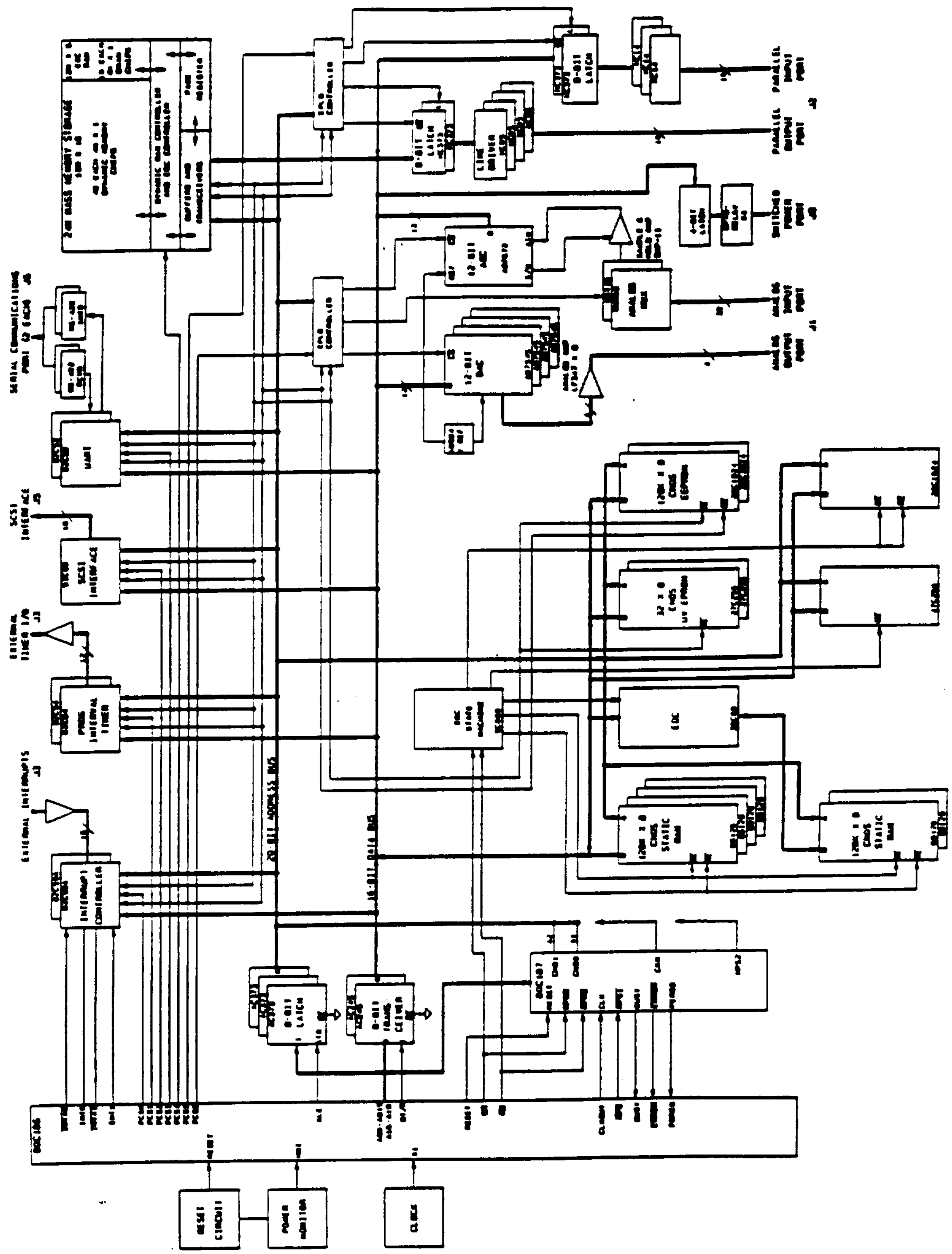


Figure 3.2-1 SC-4 Single Board Spacecraft Computer Block Diagram

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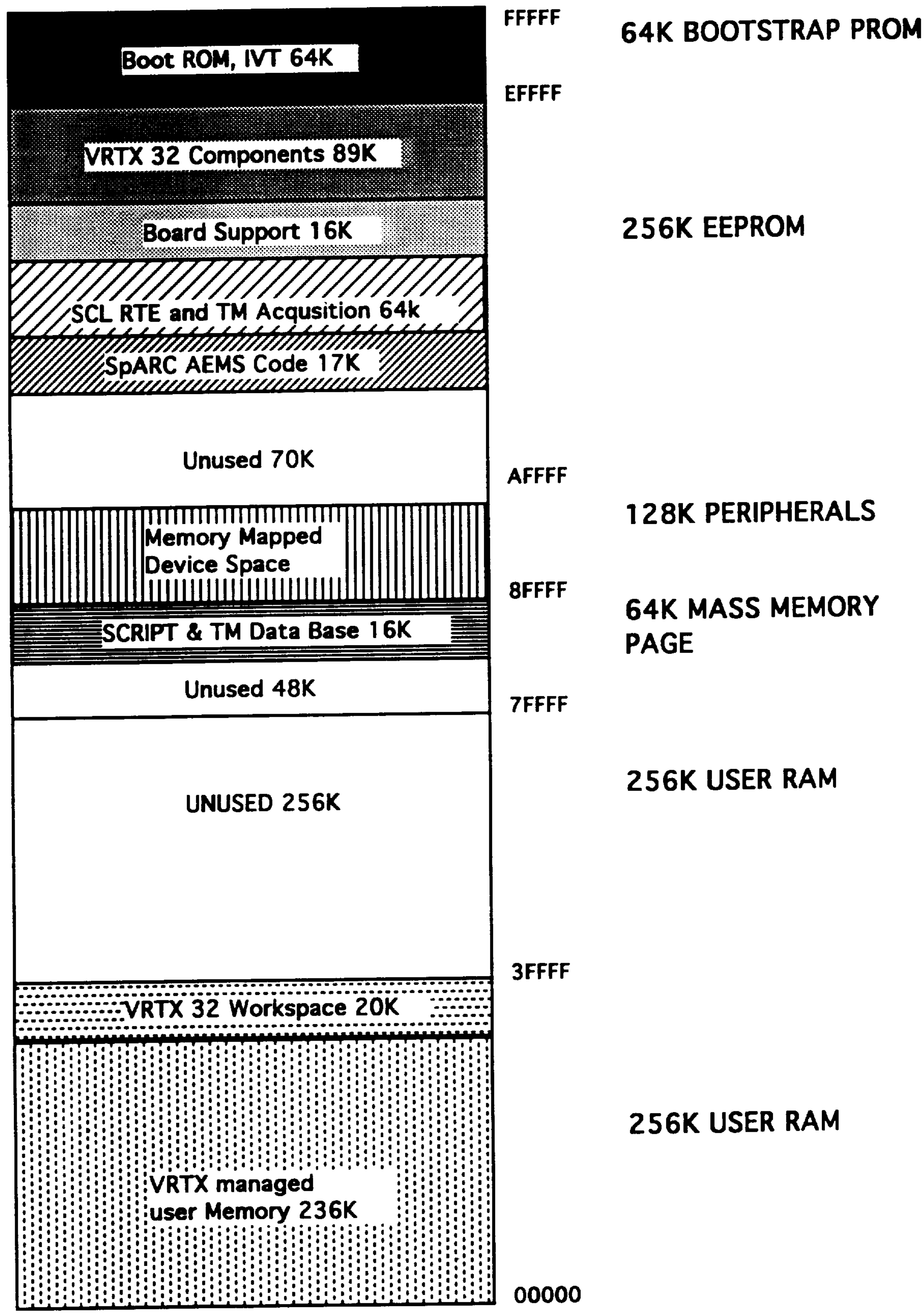
RoMPS AMS Software Summary

MODULE	VENDOR	FUNCTION	LANGUAGE
VRTX-32	Ready Systems	Real Time Executive	"C", Assembler
RTL/86 VRTX-32	Ready Systems	"C" Reentrent Run Time Library Interface	"C", Assembler
RT-SCOPE	Ready Systems	System Monitor, Debugger	"C", Assembler
RTL/86 RT-SCOPE	Ready Systems	"C" Language Interface to RT-SCOPE	"C", Assembler
SC-4 Board Support Package	ICS/SpARC	Interface Between VRTX and SC-4 Devices	"C", Assembler
Command Input	SpARC	Get Command Packets from HH Avionics	"C"
Zymate Interface	SpARC	SCL to Zymate Interface	"C"
Telemetry Acquistion	SpARC	Acquire the Data of the Telemetry Items and forward to Telemetry Reduction	"C"
Telemetry Output	SpARC	Format and send telemetry	"C"

RoMPS AMS Software Summary

MODULE	VENDOR	FUNCTION	LANGUAGE
SCL RTE	ICS	SCL Command Interpreter and Rules evaluation	"C"
Telemetry Reduction	ICS	Monitor Telemetry and post detected changes	"C"
Processing Scheduler	SpARC	Scheduled execution of scripts initiating EasyLab processing programs	SCL
Initiate Sample Processing	SpARC	Sends the EasyLab commands initiating sample processing	SCL
Initialize / Shutdown EasyLab	SpARC	Sends the EasyLab commands initiating/shutting down EasyLab	SCL
Send EasyLab Commnad	SpARC	Send an EasyLab Command	SCL

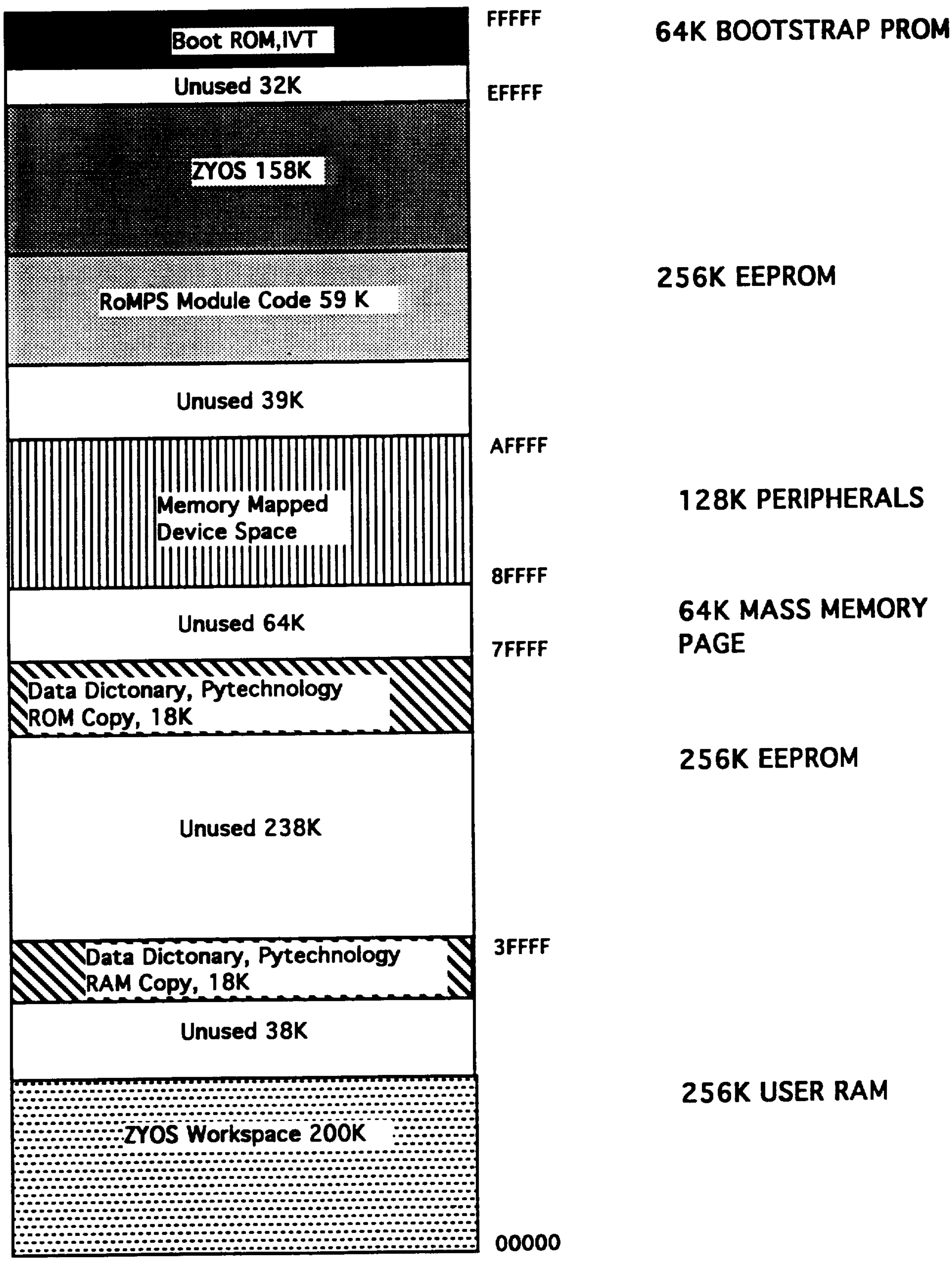
AMS Memory Map



RoMPS SC-4 EasyLab Software Summary

MODULE	VENDOR	FUNCTION	LANGUAGE
ZYOS	Zymark	Zymate Operating System	"C", PLM 86
Boot ROM	Zymark	Operating System Initialization	"C", PLM 86
Robot Module	SpARC	High level robot controller and servo interface	"C"
Annealer Module	SpARC	Oven controller interface	"C"
Annealer PyTechnology	SpARC	Annealer control variables and navigation routines	EasyLab
Rack Pytechnology	SpARC	Rack navigation routines and variables	EasyLab
Robot PyTechnology	SpARC	Robot control and navigation variables	EasyLab

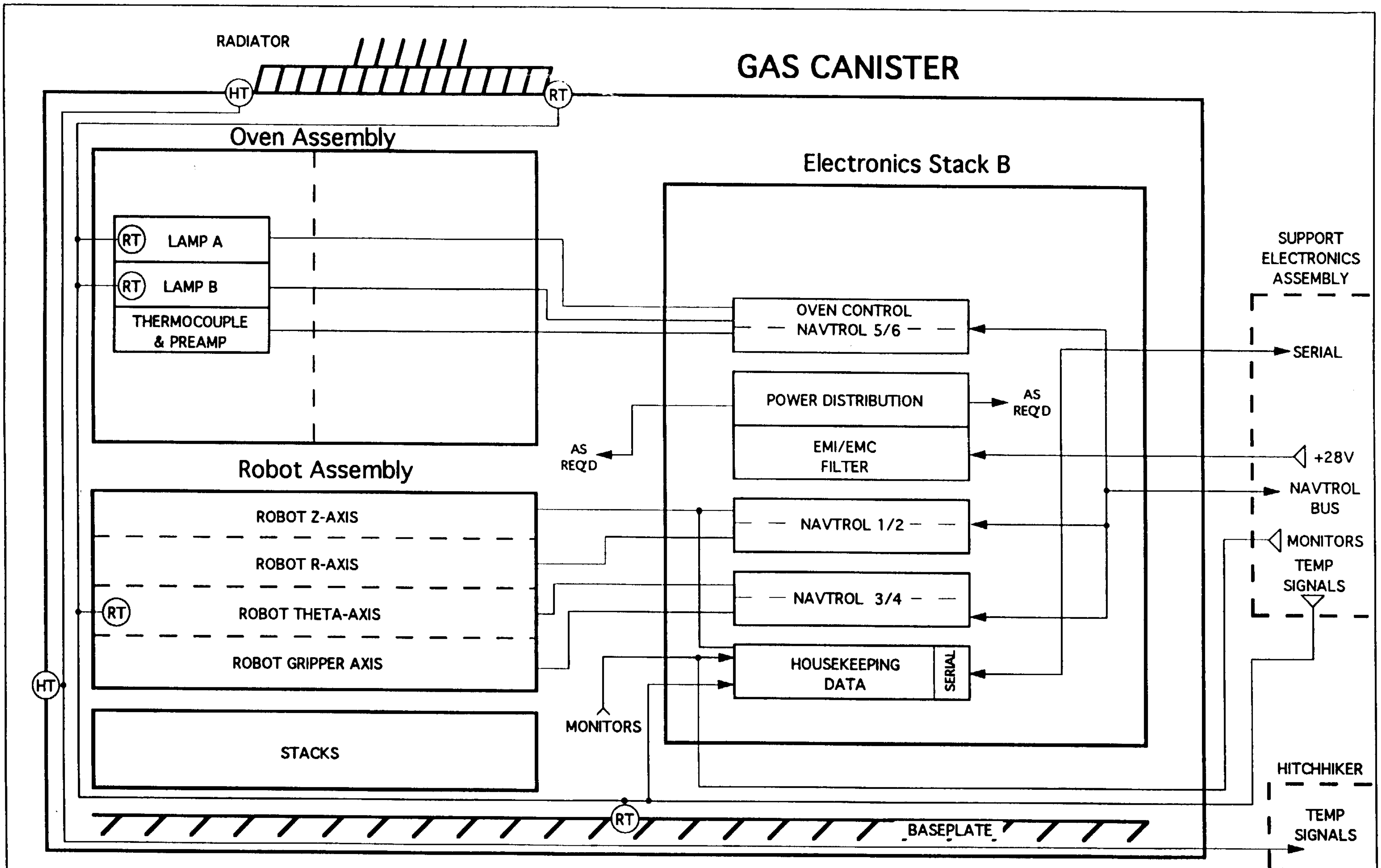
SC-4 EasyLab System Memory Map



Processor Utilization

- RoMPS sample thruput limited by annealing time
- Spacecraft Command Language
  Compiled script — 300 lines/second
- EasyLab
  Interpreted procedure — 10 lines/second
- Memory Margin — 37 %

34A



(HT) HITCHHIKER TEMPERATURE SENSOR

(RT) RoMPS TEMPERATURE SENSOR

ENGINEER M.E. DOBBS	DRAFTSMAN G. WASSICK	
SPACE AUTOMATION & ROBOTICS CENTER ENVIRONMENTAL RESEARCH INSTITUTE of MI ANN ARBOR, MI	Block Diagram 1/2 GAS Canister Subsystem RoMPS 010-342	07/02/91 DATE

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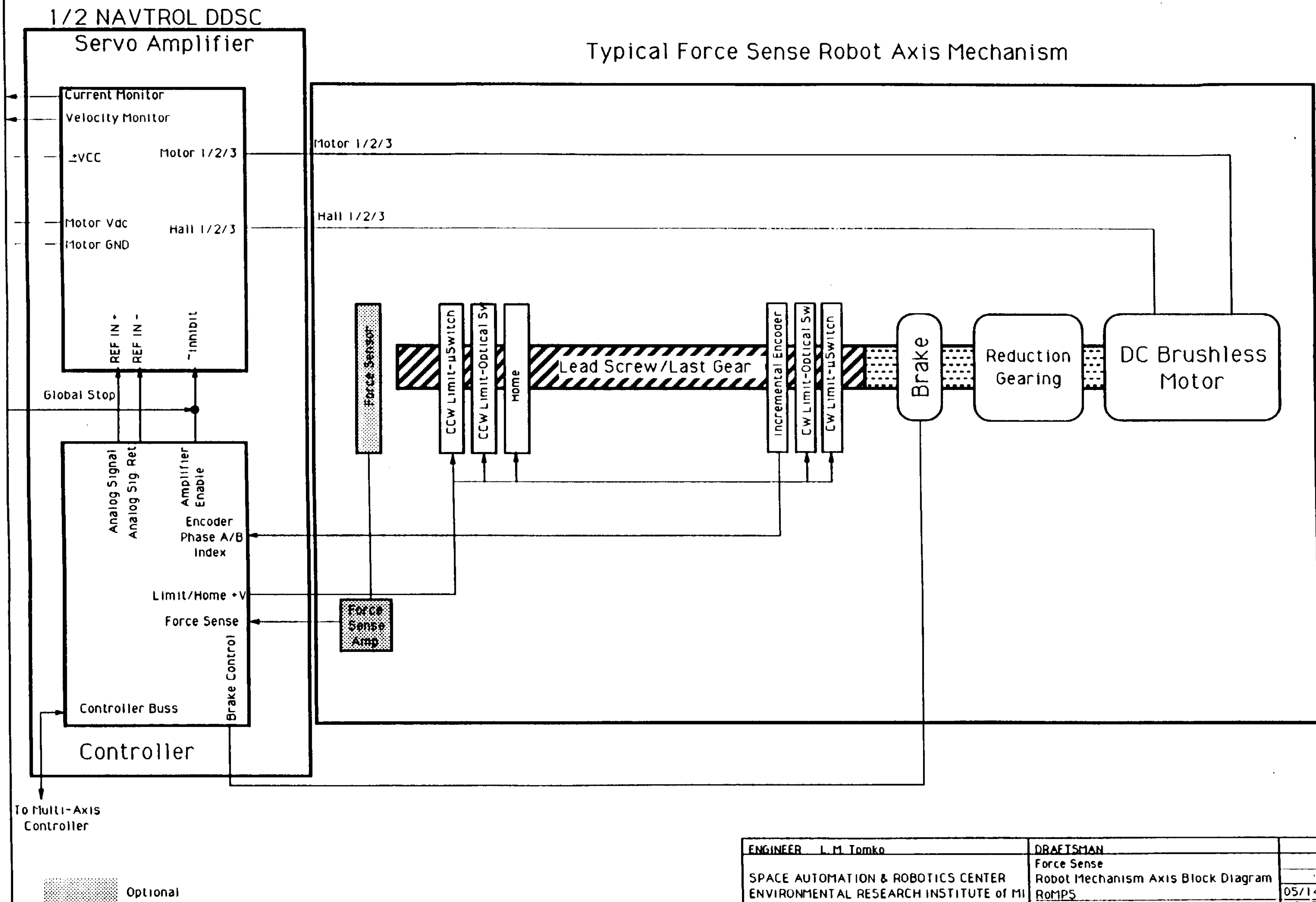
Robot Control Subsystems

- 4 Degree-Of-Freedom Material Processing Robot
  - elevation, azimuth, reach, gripper axis
    - brushless dc motors
    - hall effect commutation
    - normally-on electrical brakes
    - quadrature output incremental position encoders
    - end-of-travel fiducials
    - current or force limited
    - compliant gripper
  - sequential operation

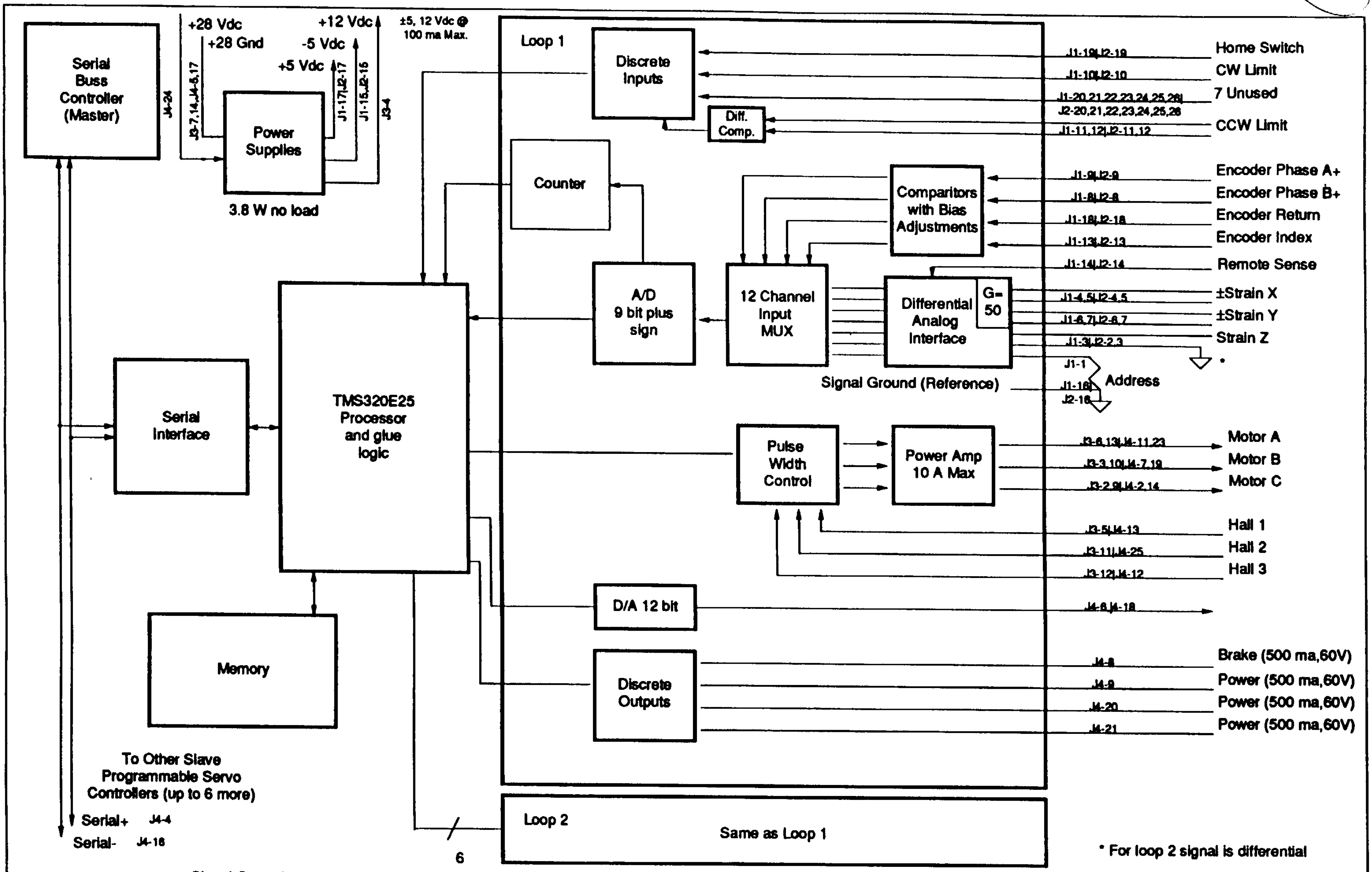
- Digital Servo Position Control
  - positioning accuracy +- 0.025 inch
  - velocity range 0.1 to 2.0 inches/sec
  - force limiting +- 1 lbf
  - Proportional-Integral-Deriviative algorithm
  - <5 msec control loop cycle time

- PWM Drive Amplifier
  - chassis isolated output stage
  - 32 volt maximum phase voltage
  - 10 amp maximum phase current
  - fold-back current limiting
  - over-temperature protection
  - output inhibit



ENGINEER L. M. Tomko	DRAFTSMAN	
SPACE AUTOMATION & ROBOTICS CENTER	Force Sense	
ENVIRONMENTAL RESEARCH INSTITUTE of MI	Robot Mechanism Axis Block Diagram	
ANN ARBOR, MI	RoMPS	05/14/91
	010-112	DATE

37



ENGINEER L. M. Tomko	DRAFTSMAN	
SPACE AUTOMATION & ROBOTICS CENTER ENVIRONMENTAL RESEARCH INSTITUTE of MI ANN ARBOR, MI	Navtrol Controller Block Diagram RoMPS 010-114	07/09/91 DATE

3.4

37A

Servo Axis Control Logic Suppliers

Functional Characteristic	Navtrol	Zymark	Industrial	uC
control algorithm	custom	custom	pid	pid
control loop rate	1.6 ms	5 ms	5 ms	5ms
number of channels/unit	2	6	1	1
commandable pid parameters	no, ucode	rom'd	yes	yes
trajectory mode	yes	no	no	no
cpu	32020	80186	several	NEC
embedded code rom'd	no	yes	yes	yes
edc ram	no	no	no	no
position detection	pot,incr	pot+incr	incr.	incr.
auxilary inputs/outputs	yes/yes	yes/no	yes/yes	yes/no
standard functions	no	yes	yes	yes
interface library	no	yes	yes	yes
host i/o	AT bus	rs422	rs422	parallel
printed circuit board	smc	dip	dip	smc
temperature range	industrial	industrial	industrial	industrial
883	no	no	no	no
883 available 1:1	no	yes	no	no
industrial heritage	no	1800 units	yes	yes
flight heritage	pending	no	no	no
industrial cost	5k	tbd	2.5k	0.25k
mil-spec cost	na	na	na	na
883B cost	>200k	>50k?	na	na

Servo Axis Control Logic Suppliers

Functional Characteristic	Navtrol	Zymark	Industrial	uC
minimum modifications required	rom'd code, interface library of standard functions	10amp power drivers	workmanship	separate current amplifier

V

Annealing Oven Control Subsystem

- Interfaces
  - Control — serial interface
  - Feedback — conditioned thermcouple output
  - Output — quartz halogen filament lamp
  - Protection — filament inrush protection

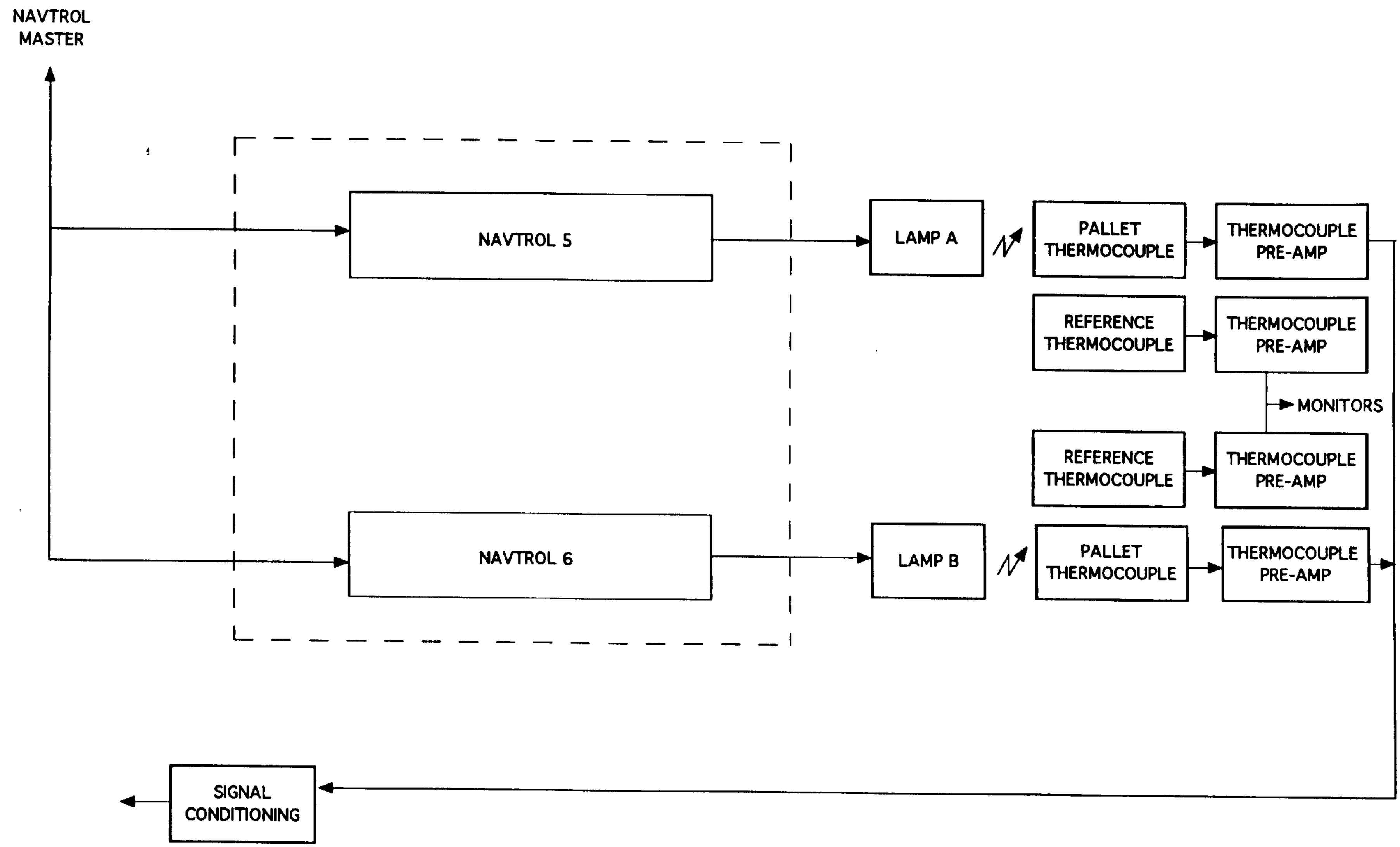
- Power Requirements
  - Voltage — 24 volt rated lamp
  - Current — 10 amp maximum

- Temperature Set Point
  - Range — 350°C to 1500°C
  - Resolution — +- 2% of setpoint (6 bits)
  - Repeatability — +- 2% of setpoint (6 bits)

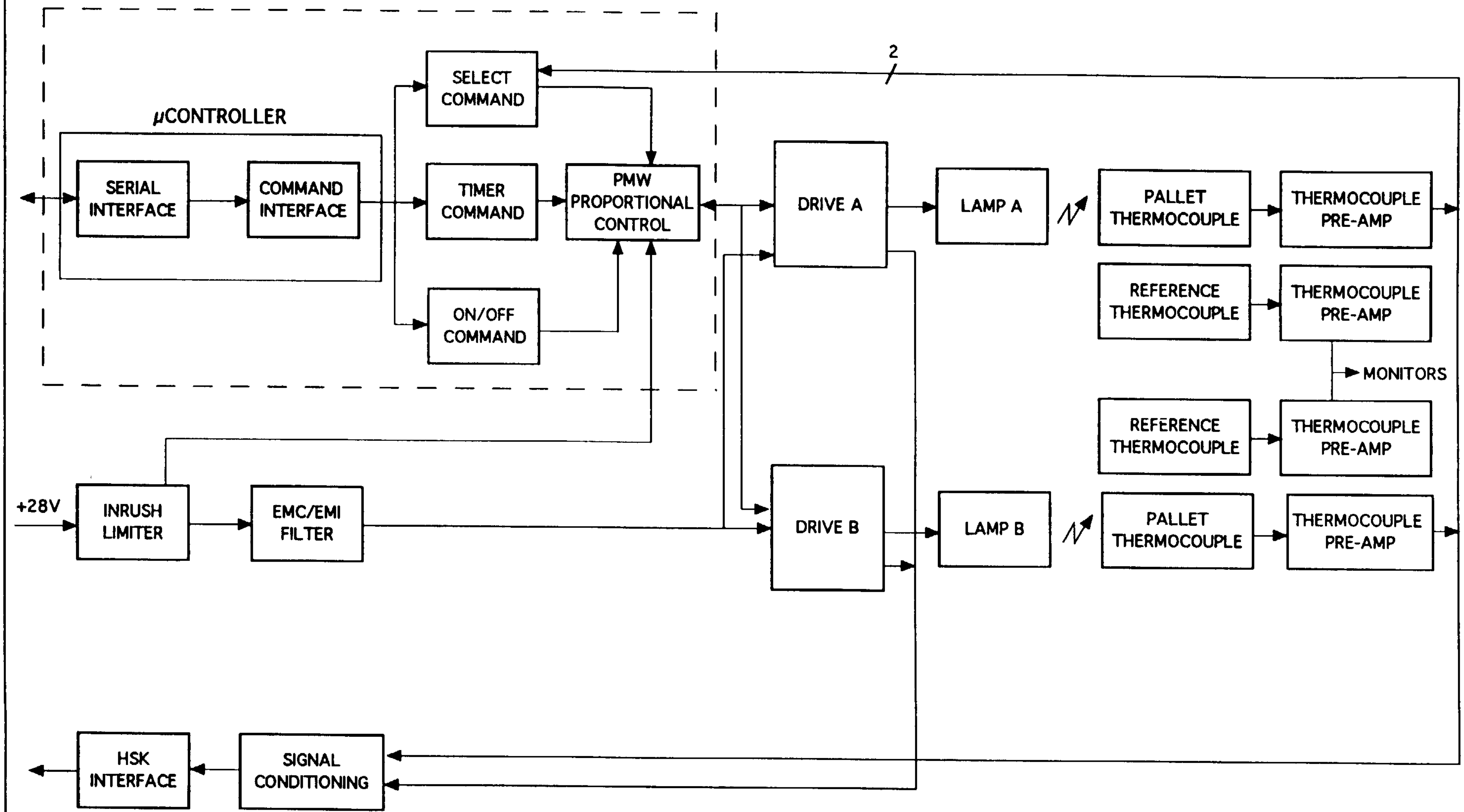
- Time Set Point
  - Range — 3 to 7200 seconds
  - Resolution — +- 1 second (software controlled)

- Response Time
  - limited by thermal coupling to sample

- Time Profile
  - 2 step time-temperature profile
    - 1) preheat, 2) melt



ENGINEER M. E. Dobbs	DRAFTSMAN G. Wassick	
SPACE AUTOMATION & ROBOTICS CENTER ENVIRONMENTAL RESEARCH INSTITUTE of MI ANN ARBOR, MI	Oven Control Block Diagram RoMPS 010-343	08/13/91 DATE

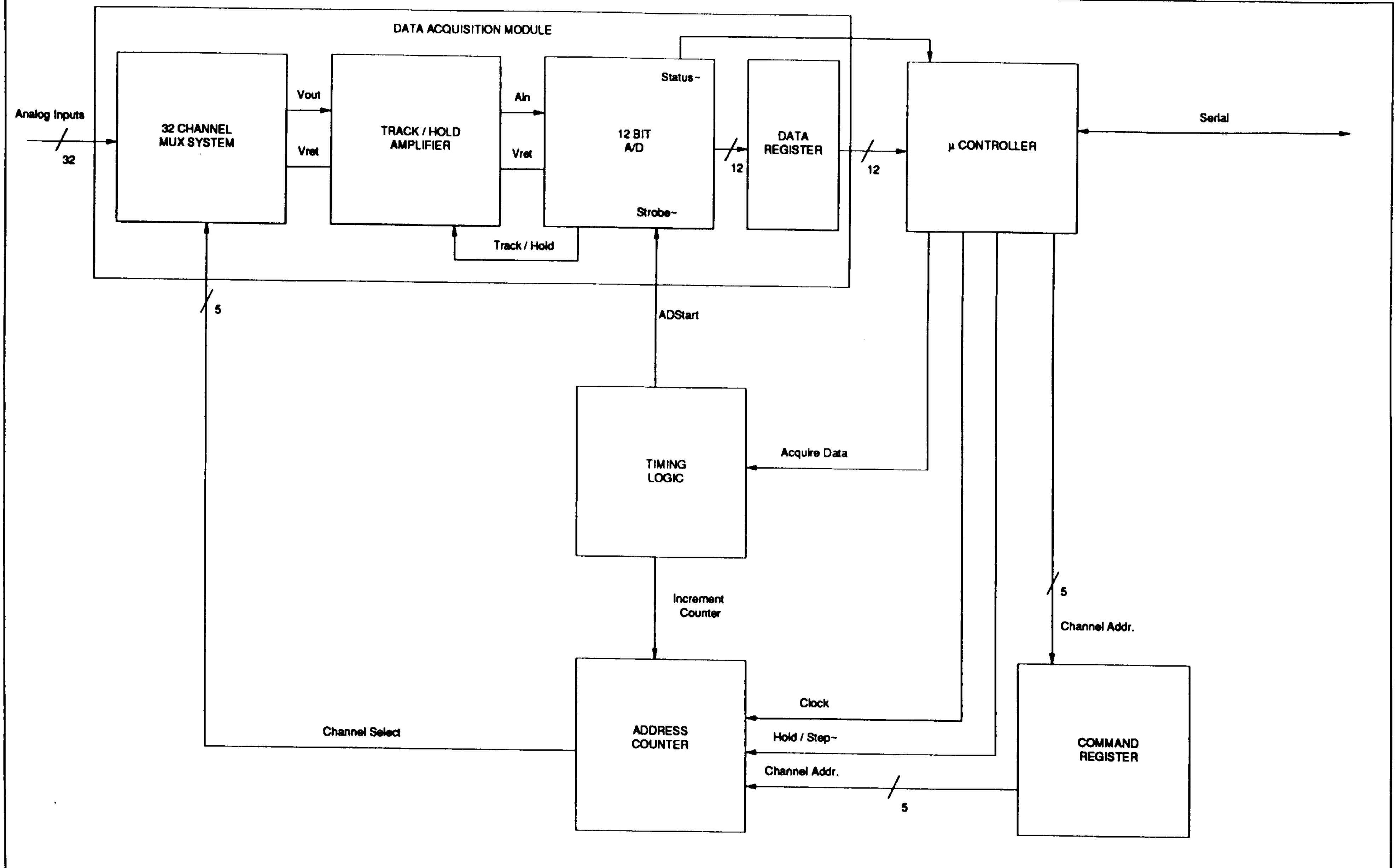


ENGINEER M. E. Dobbs	DRAFTSMAN G. Wassick	
SPACE AUTOMATION & ROBOTICS CENTER ENVIRONMENTAL RESEARCH INSTITUTE of MI ANN ARBOR, MI	Oven Control Block Diagram RoMPS 010-344	10/10/91 08/13/91 DATE

15.0B

Experiment Data Acquisition Subsystem

- RTA process monitor
    - thermocouple lamp flux monitors
- Oven Status
    - lamp current
- Robot Status
    - 4 axis position
    - 1 axis force
    - EOT fiducials
    - overtemp, current limit indicators
- Computer Status
    - executive status
    - script status
    - rule evalutation
- Health and Safety Monitors
    - radiator
    - oven
    - robot
    - electronics stacks
    - power supplies

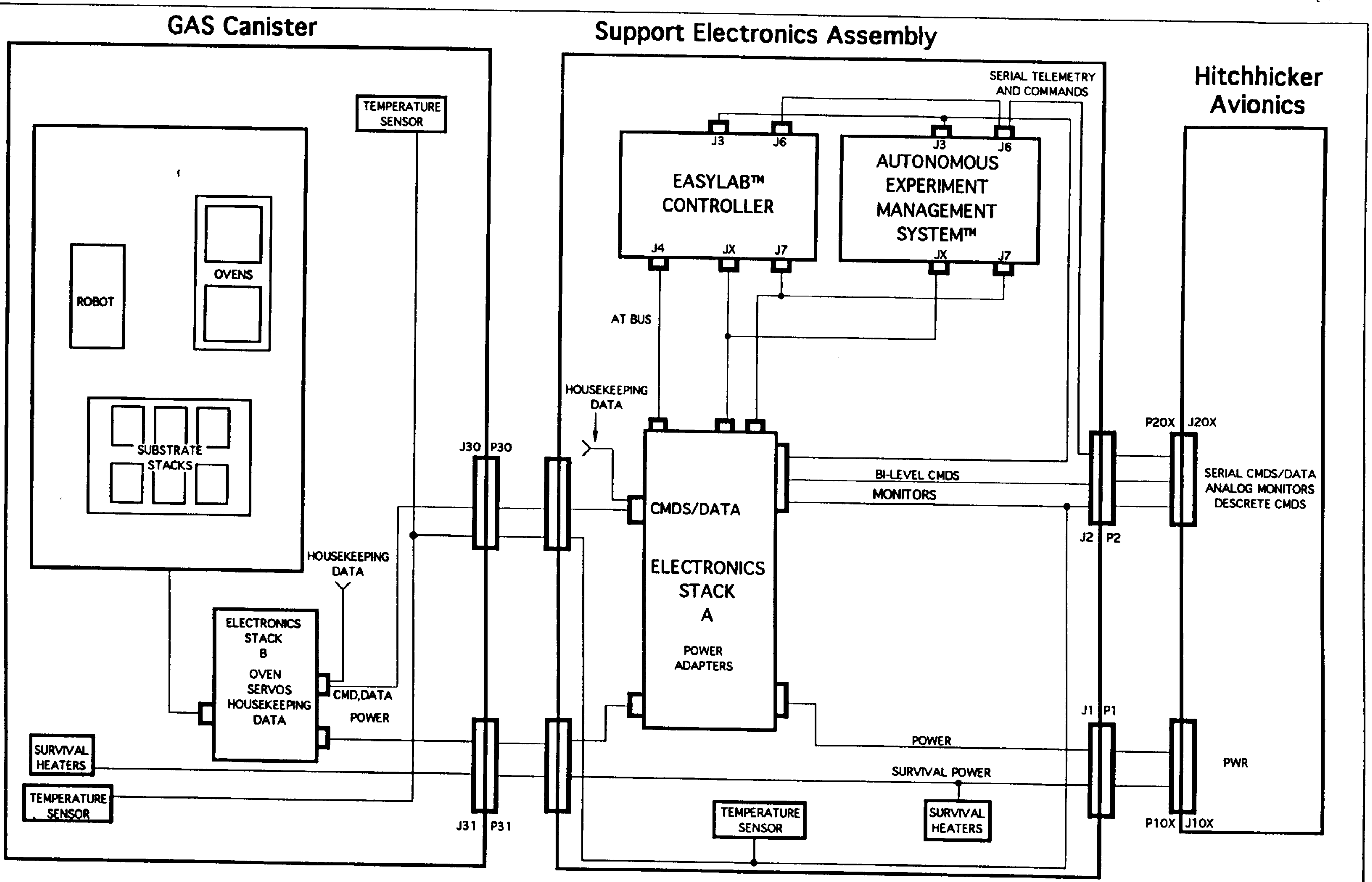


ENGINEER L. M. Tomko	DRAFTSMAN	
SPACE AUTOMATION & ROBOTICS CENTER ENVIRONMENTAL RESEARCH INSTITUTE of MI ANN ARBOR, MI	Housekeeping Data Acquisition Block Diagram RoMPS 010-338	10/10/91 07/16/91 DATE

4c

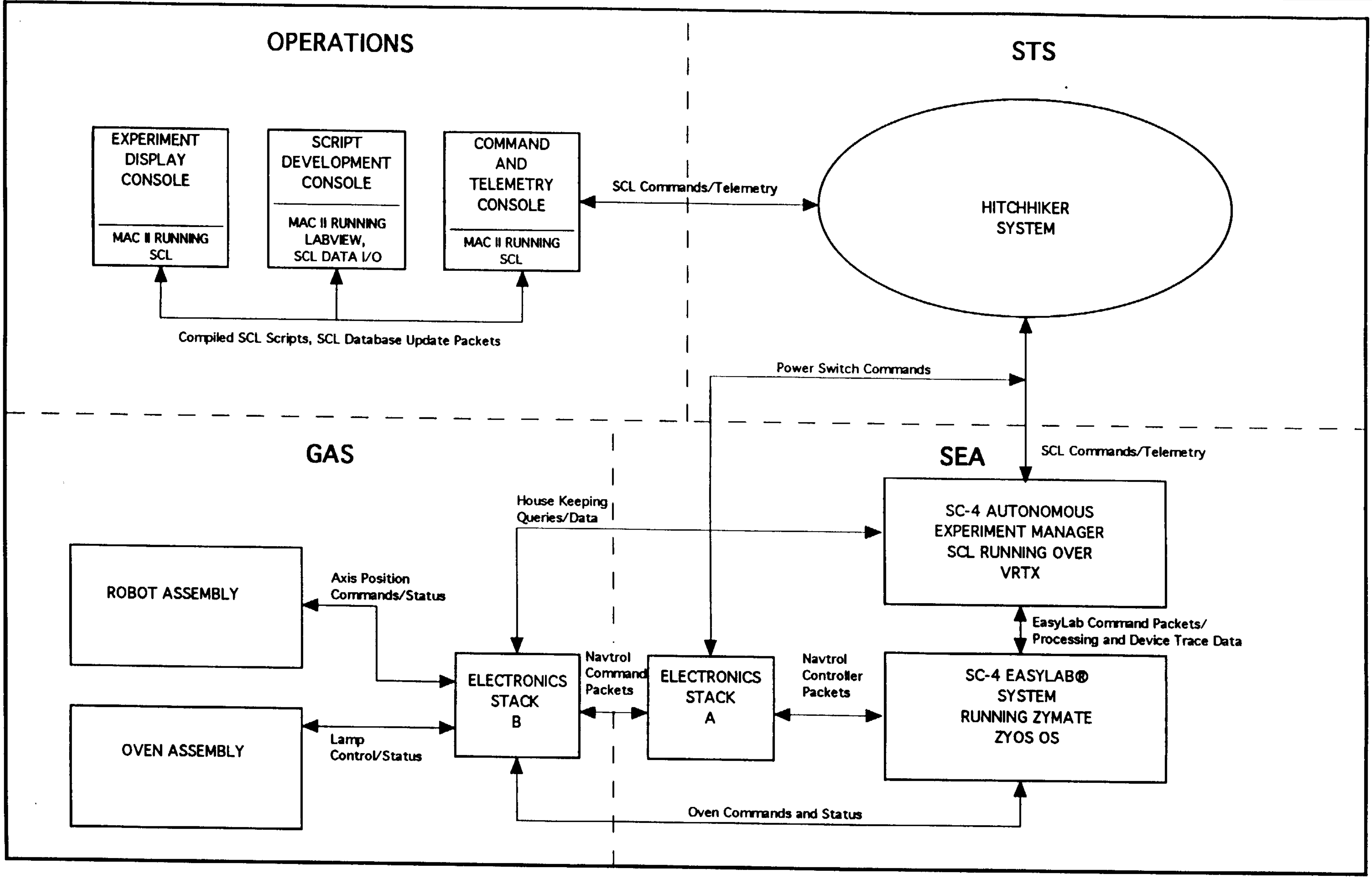
RoMPS Data Acquisition List

	A	B	C	D	E
1	RoMPS Data	Acquisition			
2	Function	Description	Length	Rate	Comment
3					
4		sample temp	2	1	process
5		flux intensity	2	1	
6		flux intensity	2	1	
7		flux intensity	2	1	
8		flux intensity	2	1	
9		lamp current	2	1	
10		force	2	1	robot
11		eot status	2	1	
12		exp. current	2	1	engineering
13		elec temp	2	1	
14		elec temp	2	1	
15		radiator temp	2	1	
16		oven temp	2	1	
17		oven temp	2	1	
18		robot temp	2	1	
19					
20					
21					
22					
23					
24	TOTAL		30		



Note: The designation "P" means this connector is on the end of a cable.
The designation "J" means this connector is on a chassis mount connector.
PLUG JX IS 1553 OR nRS422

ENGINEER L. M. Tomko	DRAFTSMAN	
SPACE AUTOMATION & ROBOTICS CENTER ENVIRONMENTAL RESEARCH INSTITUTE of MI ANN ARBOR, MI	Interface Connectors Harnessing RoMPS 010-140	10/10/91 06/07/91 DATE



ENGINEER M. F. Dobbs	DRAFTSMAN	
SPACE AUTOMATION & ROBOTICS CENTER ENVIRONMENTAL RESEARCH INSTITUTE of MI ANN ARBOR, MI	RoMPS OPERATIONAL CONCEPT RoMPS 010-337	10/10/91 DATE